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DR. THOMSON'S

SYSTEM OF CHEMISTRY.

Part the Third.

SEVENTH EDITION.

VOLUME II.

OUTLINES

OF

MINERALOGY, GEOLOGY,

AND

MINERAL ANALYSIS.

BY THOMAS THOMSON, M.D.

REGIUS PROFESSOR OF CHEMISTRY IN THE UNIVERSITY OF GLASGOW, F.R.S. LONDON AND EDINBURGH, F.L.S. F.G.S. MEMBER OF THE CAMBRIDGE PHILOSOPHICAL SOCIETY, OF THE CAMBRIAN NATURAL HISTORY SOCIETY, OF THE IMPERIAL MEDICO-CHIRURGICAL AND PHARMACEUTICAL SOCIETIES OF ST. PETERSBURGH, OF THE ROYAL ACADEMY OF SCIENCES OF NAPLES, OF THE MINERALOGICAL SOCIETY OF DRESDEN, OF THE CÆSARIAN NATURAL HISTORY SOCIETY OF MOSCOW, OF THE LITERARY AND PHILOSOPHICAL AND NATURAL HISTORY SOCIETIES OF NEW YORK, OF THE NATURAL HISTORY SOCIETY OF MONTREAL, ETC. ETC.

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VOL. II.

PART II.

OF GEOLOGY.

INTRODUCTION.

The *Earth* is one of eleven bodies called planets, which revolve round the sun. Its mean distance from that luminary is 93,595,000 English miles; its mean diameter is 7,912 miles; and its mean circumference 24,856 miles. It completes its diurnal revolution in 24 hours; and its annual revolution in 365 days, 5 hours, 48 minutes, and 51 seconds. One satellite or attendant body, the *Moon*, 2,180 miles in diameter, revolves round the earth in 29 days, 12 hours, and 44 minutes, at a mean distance of 475,000 English miles. The moon, like the earth, exhibits a surface of mountains and valleys. But it can have no atmosphere, or at least the density of its atmosphere can only be $\frac{1}{3000}$th of that of the earth; so that it can only support a column of mercury 0·006 inch in height, which is considerably beyond the highest vacuum that can be produced in our best constructed air pumps.

The earth is not a perfect sphere but an oblate spheroid, or sphere flattened at the poles. The amount of the compression is such, that the *equatorial* diameter exceeds the *polar* diameter or *axis* by about 25 miles; or the one is to the other very nearly as 312 to 311.

The centrifugal force arising from the revolution of the earth round its axis, which obviously tends to dilate the equatorial parts, led Newton to infer the oblate or compressed figure of the earth, before it had been ascertained by actual measurement. He calculated the ellipticity from theory at

$\frac{1}{230}$th of the axis, which is almost $\frac{1}{3}$d greater than the truth. A homogeneous fluid body of the mean density of the earth, and making its diurnal revolution in the same time, would in fact have the proportions which Newton supposed, and the ellipticity in that case would be a *maximum.*

But if the earth, instead of being homogeneous, increase in density as we approach the centre, the compression in that case is not so great. Mathematicians have shown, that if the density were to increase so as to be infinitely great at the centre, the ellipticity in that case would be a *minimum*, and would amount only to $\frac{1}{578}$.

From the observations made at Schechallian by Dr. Maskelyne, it has been shown by Dr. Hutton, that the mean specific gravity of the earth is not under 4·75. Now, the mean density of the external surface of the earth (to which alone we have access) is not so high as 2·75; so that the mean density is nearly twice as great as that of the surface. Hence it is obvious that the specific gravity must increase as we advance from the surface towards the centre. If we suppose the specific gravity of the centre about 12, and that the specific gravity increases nearly regularly from the surface to the centre, we would obtain a mean specific gravity nearly equal to that of the earth. If this supposition be well founded, the figure of the earth is a spheroid of equilibrium. The ellipticity of such a spheroid would be intermediate between that of a homogeneous globe and that of a globe having an infinitely high specific gravity in the centre. Now, as this accords with fact, we are entitled to infer that the earth approaches very nearly to a spheroid of equilibrium, if it does not, as is more probable, coincide with it entirely.

It is evident, that whatever causes gave this oblate figure to the globe, have acted upon the *solid* as well as the fluid *parts.* The land, in a general point of view, is as much elevated at the equator as towards the poles. But, since the equatorial regions are 12 miles farther from the centre than the parts at the pole, it is obvious, that if the solid nucleus of the globe were a true sphere, the sea would be accumulated by the centrifugal force in the equatorial regions, which would have been completely submerged while the polar regions would have been left dry and elevated many miles above the level of the waters. The ocean would have formed a broad and deep zone round the equator, separating the two continents encircling the poles.

The figure of the earth shows that the whole globe was originally fluid. At the time of its consolidation, it must have had the same axis that it has at present. Hence those geologists, who, about the middle of the 18th century, accounted for the fossil remains of animals and plants belonging to the torrid zone in Siberia and other frozen regions of the globe, by supposing that the axis of the earth may have changed its position, have started an hypothesis inconsistent with the mathematical constitution of the globe, and therefore erroneous.

Laplace was of opinion, that the precession of the equinoxes and the nutation of the earth's axis, indicate a gradual increase of specific gravity from the surface to the centre. This is the way that the materials would have arranged themselves, on the supposition of their having existed in a state of liquidity. The heaviest would occupy the centre, and the rest would arrange themselves in the order of their specific gravity. Now, the only bodies known to us as possessing a specific gravity equal to 12, or that of the central nucleus, are certain metallic bodies. Does this circumstance warrant the conjecture that the central parts of the earth are composed of metallic bodies, and give probability to the opinion of Beccher, that the veins of metallic ores found near the surface, are minute offsets from these central proportions?

CHAP. I.

OF THE TEMPERATURE OF THE EARTH.

THE mean temperature of the air, overland, nearly on a level with the sea at the equator, is reckoned by Humboldt 81°·5.* The mean temperature of latitude 45° in Europe is 56°. At the pole, judging from the observations of Parry, the mean temperature cannot exceed —13°.†

The mean temperatures of places in Western Europe, differ very considerably from those on the Eastern side of America and of Asia. This will appear evident by inspecting the following table:—

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* It would appear that the temperature of places in the torrid zone, differs a little according to situation. The following table of Boussingault, drawn up partly from his own observations and partly from those of Humboldt and Captain Hall, shows this:—

Ports.	Latitude.	Mean Temperature.
Cumana, .	10° 27′ N.	81°·5
La Guayra, .	10 37	81 ·5
Rio Hacha, .	11 40	82 ·58
Sta Marta, .	11 15	83 ·48
Barranquilla, .	11 0	82 ·22
Carthagena, .	10 25	81 ·5
Panama, .	8 58	80 ·96
Tumaco, .	1 40	78 ·98
Esmeraldas, .	0 55	79 ·52
Guayaquil, .	2 11 S.	78 ·80
Payta, . .	5 5 S.	80 ·78

See Ann. de Chim. et de Phys. liii. 235.

Boussingault found, that in the torrid zone, the earth, a foot below the surface, possessed the mean temperature of the year.

† The following mean temperatures have been deduced from the observations of Parry and Franklin:—

	Latitude.	Mean Temperature.	
Melville Island, .	74°¾	—1°½	Parry.
Port Bowen, . .	73 ¼	+4	Do.
Igloolik, . .	69 ⅓	+7	Do.
Winter Island, . .	66 ¼	+9 ½	Do.
Fort Enterprize, .	64 ½	+15½	Franklin.

Places.	Situation.	Latitude.	Mean Temperature.
Enontekis and Uleo,	Lapland,	66° to 68°	32°
Table Bay,	Labrador,	54°	
Stockholm,	Sweden,	60°	41
St. George's Bay,	Newfoundland,	48°	
Belgium,	Europe,	51°	50
Boston,	America,	42° 30′	
Rome and Florence,	Italy,	43°	59
Raleigh,	Carolina,	36°	
Pekin,	Asia,	39° 54′	55 ½

In the torrid zone the mean temperature of the surface of the sea is higher than that of the atmosphere.

Perrings found it	82°·76
Quevedo, .	83 ·48
Chornea, .	83 ·66
Rodman, .	83 ·84
Humboldt, .	84 ·74
Mean, .	83 ·7

Or, about two degrees higher than that of the air.*

In the immense valley of the Mississippi to the west of the Allegany mountains, the mean temperatures are nearly the same as in the corresponding latitudes on the Atlantic; but the winters are not so cold nor the summers so hot. The mean temperatures of the west coast of America appear to correspond with the mean temperatures of the western parts of Europe.

The following table, drawn up by Humboldt, exhibits the mean temperature of winter and summer in places having the same mean annual temperature; it shows the great diversity which exists in this respect in different parts of the earth:—

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* At great depths even in the torrid zone the temperature of the water is low. Thus, Captain Foster found the temperature of the Atlantic near the equator 80° at the surface, and 44° at the depth of 400 fathoms. (Webster's Narrative, Vol. i. p. 27.) Off Cape Horn, on the 2d January, 1829, the temperature of the surface of the sea was 39°, and at the depth of 900 fathoms 34°. (Ibid. p. 134.)

Mean Temper.	Latitude N.	Longitude.	Situation.	Mean Temper.	
				Winter.	Sum.
68°	29° 30′	84° 20′·5 W.	Florida	53°·6	80°·6
	32 37	19 6½ W.	Madeira	63 ·5	72 ·28
	36 48	49 23 E.	Africa	59	80 ·6
63 ·5	32 30	92 9 23″ W.	Mississippi	46 ·4	77
	40 50	12 0 23 E.	Italy	50	77
59	35 30	86 21 W.	Ohio Basin	39 ·2	77 ·9
	43 30	1 to 2 E.	France	44 ·6	75 ·2
54 ·5	38 30	86 51 W.	America West	34 ·7	75 ·2
	40	76 21 W.	America East	32 ·54	77
	47 10	3 43 W.	France	41	68
	45 30	7 9 E.	Lombardy	34 ·7	73 ·4
	40	113 51 E.	Asia East	21 ·46	88 ·4
50	41 20	86 31 W.	America West	31 ·1	61 ·6
	42 30	73 21 W.	America East	30 ·2	73 ·4
	52 30	9 9 W.	Ireland	39 ·2	59 ·54
	53 30	3 9 W.	England	37 ·8	62 ·6
	51	0 9 E.	Belgium	36 ·5	63 ·5
	40	113 51 E.	Asia East	21 ·46	88 ·4
45 ·5	44 42	73 29 W.	America West	23 ·9	61 ·6
	57	4 39 W.	Scotland	36 ·14	56 ·48
	55 40	10 24 E.	Denmark	30 ·74	62 ·6
	53 5	19 9 E.	Poland	28 ·04	66 ·2
41	47	73 21 W.	Canada	14	68
	62 45	7 9 E.	Norway	24 ·8	62 ·6
	60 30	15 9 E.	Sweden	24 ·8	60 ·8
	60	22 9 E.	Finland	21 ·46	63 ·5
	58 30	34 9 E.	Russia	13 ·1	68
36 ·5	50	73 51 W.	Canada	6 ·8	60 ·8
	62 30	15 54 E.	G. of Bothnia	17 ·6	57 ·2
	62 5	20 9 E.	G. of Bothnia	16 ·7	59
32	53	59 51 W.	Labrador	3 ·2	51 ·8
	65	17 39 E.	Sweden	11 ·3	53 ·6
	71	23 9 E.	Norway	23 ·9	44 ·7

The temperature of the southern hemisphere is nearly the same as that of the northern, from the equator to the latitude of 40°.[*] Beyond that the mean temperature perhaps does not differ much from that of the corresponding northern latitude. But the summers are much colder, while the winters are as much milder. This is owing to the great preponderance of sea over land in the southern hemisphere.

The preceding remarks apply only to the temperature of those parts of the earth that are nearly as low as the surface of the sea; but as we ascend into the atmosphere the temperature constantly diminishes, so that even in the torrid zone, at a certain elevation, we come to the region of perpetual congelation. The cause of this diminution of temperature is the expansion of the air in proportion to its elevation, which occasions an increase in its capacity for heat and a consequent lowering of its temperature. This diminution is partly counteracted by large masses of earth, which communicate heat to the air. Hence in extensive table-lands the temperature is not quite so low as it would be if the air were at a distance from the surface of the earth. This is probably the reason why the temperature in Mexico and in Peru diminishes according to the observations of Humboldt only one degree of Fahrenheit for every 495 feet of elevation; while in this country, according to the observations of Dr. Hutton of Edinburgh, the diminution amounts to 1° for about 268 feet of elevation. He kept a thermometer on the top of Arthur's Seat and another at Leith, near the level of the sea, for three years. The mean difference between the two was about 3°, and the height of Arthur's Seat, above the level of the sea, is very nearly 803 feet.

How far the temperature of the earth has remained permanent, or whether it has undergone any alteration since the commencement of history, is a question which cannot easily be determined. From the account of the climate near the Black Sea, given by Ovid in his Tristia, and from various passages in the ancient Roman writers, it has been inferred by some that the climate is milder now, at least in Europe, than it was about 2000 years ago. Others have drawn a

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[*] The mean temperature at Paramatta, in New South Wales, as determined by Sir Thomas Brisbane, is 61°·⅓. That of the Cape of Good Hope is 67°. The mean summer temperature is 76°, and the mean winter temperature 60.[†]

[†] Webster's Narrative of Foster's Voyage, Vol. i. p. 316.

contrary conclusion from observations, which, however, are far from conclusive. A fortunate accident has demonstrated that the climate of Italy has undergone no sensible alteration during the course of the last two centuries. The Academy del Cimento, which may be said to have terminated its scientific labours about the year 1667, contrived a thermometer, which was reduced to Fahrenheit's scale by Dr. Martine.* In the year 1829, Signor Libri of Florence found a considerable number of these original alcoholic thermometers of the Academy, and was thus enabled to verify the reductions of Dr. Martine.† By a fortunate accident some registers of the weather kept by Raineri, a pupil of Galileo for 16 years, were discovered. By the discussion of these, with a knowledge of the true scale, Signor Libri has been able to show that no sensible change has taken place upon the climate of Florence between that period and the present, though the contrary had been suspected.‡

M. Arrago has demonstrated that during the last 2000 years the temperature of the earth cannot have varied so much as $\frac{1}{5}$th of a degree, otherwise the length of the day would have altered, which is not the case.

When we dig to a certain depth below the surface of the ground, we come at last to a situation in which if the bulb of the thermometer be put, it remains unaltered during the whole year. The heat at this depth is considered as representing the mean heat of the place at the surface of the ground. The bottom of the cavern under the Observatory of Paris is about 90 feet below the surface of the ground. A thermometer placed in it varies only about $\frac{1}{33}$th of a degree during the whole year from 52°, which is the mean temperature of Paris.

Lambert, in his Pyrometry, published in 1779, gives a set of observations made by M. Ott, in a garden near Zurich, in Switzerland. The observations were made with seven thermometers, the bulbs of which were sunk respectively 0·266 foot, 0·5325 foot, 1·065 foot, 2·13 feet, 3·195 feet, 4·26 feet, and 6·39 feet under the surface of the ground. The following table exhibits the result of these observations, which were continued for four years:—§

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* Martine's Essays, p. 38. † Ann. de Chim. et de Phys. xlv. 354.

‡ Forbes' Report on Meteorology, p. 209.

§ Ann. de Chim. et de Phys. viii. 214.

Depth of Bulbs.	Mean height of Thermo.	Minimum height.	Maximum height.	Variation.
Feet.				
0·266	50°·72	30°·92 Feb.	67°·1 July.	36°·18
0·5325	48 ·74	32 ·36 Feb.	63 ·86 July.	31 ·5
1·065	48 ·92	34 ·7 Feb.	63 ·7 July.	29 ·0
2·13	48 ·92	36 ·14 Feb.	60 ·98 July & Aug.	24 ·84
3·195	49 ·46	37 ·04 Feb.	61 ·34 August.	24 ·3
4·26	50 ·18	39 ·92 Feb.	60 ·98 August.	21 ·06
6·39	50 ·90	41 ·9 Feb. & Mar.	59 ·36 Aug. & Sep.	17 ·46

It is obvious that the mean temperature in these observations slowly increases as the bulb of the thermometer is sunk farther under the surface of the earth, and that the annual variation diminishes so much that at 6·39 feet under the surface it does not amount to half of what it is at 0·266 foot under the surface.

A set of similar observations was made in the garden of Mr. Ferguson of Raith, near Kirkaldy, in Scotland, in North latitude 56° 10′, during the years 1815, 1816 and 1817. Four thermometers were employed, the bulbs of which were respectively 1 foot, 2 feet, 4 feet, and 8 feet below the surface of the ground. The following table shows the results:—*

Depth of Bulbs.	Mean height.	Minimum.	When reached.	Maximum	When reached.	Variation.
1 foot	45°·5	33°	30th Dec.	58°	13th July.	25°
2 feet	46 ·5	36	4th Feb.	56	24th July.	20
4 feet	46 ·5	39	11th Feb.	54	2d Aug.	15
8 feet	46 ·75	42	16th Feb.	51½	12th Sept.	9½

The years of observation happened to be colder than usual. Hence the mean was below that of the atmosphere at Kirkaldy, which is 47°·7. The variation diminishes as the thermometers are sunk deeper, and the time of the minimum and maximum is farther distant from the winter and summer solstices according to the depths.

A set of observations on this subject has been lately made by M. Gerhard in Prussia, between North latitude 50° and 51°½. He took advantage of the shafts to coal and other mines in that country, and placed the bulbs of his thermometers at some little distance from these shafts (when possible),

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* Leslie, article *Climate*, in Supplement to Encyclopædia Britannica, 6th edition. Vol. iii. 179.

and covered with earth to exclude, as far as could be done, the action of the air. The following table exhibits the results:*—

Names of Places.	Height of do. above the sea in feet.	Depth of Therm. under surface in feet.	Mean temperature	Annual variation.	
Robeshaft, near Tornowitz, in Dalomate.	1062	34	46°·08	2°·25	1
Annashaft, coal mine by Czernitz.	914·8	47·8	46 ·19	10 ·125	2
Coal mine near Bielschowitz.	1026·75	29·3	46 ·37	2 ·8	3
Catherineshaft, coal mine by Ruda.	930·9	35·5	47 ·04	6 ·75	4
Frahlicheranblick, copper mine.	1519·7	67·5	44 ·46	2 ·25	5
Gotthillshaft, Löbejüne, coal mine.	3026·7	58·15	48 ·72	6 ·19	6
Shaft T, copper slate, near Eisleben.	507	34	47 ·93	1 ·8	7
Gopelshaft coal mine, Trappe.	694·7	28·2	47 ·23	0 ·83	8
Josinashaft coal mine, near Wetter.	264·97	30·78	48 ·31	12 ·6	9
Kniggelweger, sparry ironstone.	1414·32	34	45 ·14	5 ·29	10
Luftshaft coal mine, Herzogenrath.	319·8	27·37	47· 91	3 ·371	11

The great difference in the height of the localities in this table above the sea, prevents us from seeing whether the temperature increases as we descend, as it does in the observations at Raith. The great inequality of the annual variation, from 0·83° to 12°·6, shows that the thermometers were not completely excluded from the action of the air, as they were at Raith; had they been so the variation at the depth of 67·5 feet would have been almost nothing. The variation of the thermometer (No. 8,) at 28·2 feet below the surface was only 0·83°, while that of No. 9 at 30·78 feet was 12°·6. The

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* Poggendorf's Annalen, xxii. 497.

former must have been much more completely screened from the action of the air than the latter.

It is obvious from the preceding observations that at a certain depth below the surface, which does not seem much to exceed thirty feet, the thermometer remains unaltered during the whole year, and exhibits the mean temperature of the air at the surface of the ground in that locality. Hence the mean temperature of a place may be determined by that of springs flowing from a certain depth (not less than thirty feet) under ground. The wells at New York vary from 32 to 40 feet in depth, and, according to Dr. Nooth, the mean annual variation of their temperature is 2°, namely, from 54° to 56°;[*] this would make the mean temperature of New York 55°. Dr. J. Hunter informs us that the temperature of the wells at Brighton vary from 50° to 52°;[†] this would make the mean temperature of the air in that part of England 51°. Now, the mineral spring at Tunbridge wells, at no great distance from Brighton, is always of the temperature of 50°, at least I have observed it at that temperature both in winter and in summer. The great *Brennerei* spring at Upsala has an annual variation of 0·34°, and its mean temperature is 44°·07, which is the temperature of the air in that part of Sweden.[‡] The temperature of a spring at Mehedi on the river Dal in N. lat. 60°½ is constant at 42°·26,[§] which must be the mean temperature of the place. That of a spring at Medelsped in N. lat. 62°·5 is 39°·2, indicating the mean temperature of that place.[||] At Umeo in N. lat. 64° the constant temperature of a spring was 37°·22.[¶]

The following table exhibits the mean temperature at various heights in the Carpathian mountains, determined by Wáhlenberg[**] from the heat of springs:—

Height in feet above the sea.	Mean temperature.
1781	45°·23
3617	40 ·19

Thus it appears that at a certain depth below the surface of the earth a thermometer indicates the mean temperature of the air on the surface. It would seem that this depth is not much more than 30 feet, and probably no great increase of temperature is observed at the depth of 60 feet, or even a little more. But when we penetrate to a greater depth below

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[*] As quoted by Hunter; Phil. Trans. 1788, p. 53.

[†] Ibid.

[‡] Annals of Philosophy, iv. 23.

[§] Ibid. p. 102.

[||] Ibid. p. 105.

[¶] Ibid. p. 107.

[**] Ibid. vol. ix. p. 140.

the surface the temperature becomes higher than the mean of the place, and the elevation of the thermometer increases as the depth augments. This remarkable rise has been observed in all mines in which observations have been made.

Mines are generally situated in veins which usually dip down in one direction while they rise to the surface in another. In following such a vein the mine necessarily gets deeper and deeper. Mines 1000 feet below the surface are not uncommon; indeed, several of the Cornish mines are sunk to a depth of not less than 1500 feet. In such mines a constant rise of temperature is observed as we descend. Thus, at the bottom of Dalcoath mine, near Redruth, at a depth of 238 fathoms, the constant temperature is 84°, while the mean temperature of that part of Cornwall does not exceed 51°. A similar elevation of temperature has been observed by Mr. Fox in many other Cornish mines. Mr. Bald has made a similar observation with respect to the coal mines at Newcastle, most of which exceed 100 fathoms in depth. We are informed by Daubuisson that the same rule holds good in the mines of Freyberg in Saxony and of Brittany in France. Humboldt found the mines of South America in precisely the same predicament. Cordier made similar observations respecting the coal mines in the south of France, and Gerhard of those in Prussia.

I. The following tables exhibit the observations made on the Cornish mines by Mr. R. W. Fox:—*

1. *Huel Abraham—December*, 1815.

Depth in Feet.	Temp. of Air and Water.
0	50°
16	52
121	57
239	61
269	62
298	63
361	63½
479	64
590	Air, 66
	Water, 64
667	Air, 68
	Water, 66

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* Ann. de Chim. et de Phys. xiii. 200.

Depth in Feet.	Temp. of Air and Water.	
744½	Air,	70
	Water,	68
769	Air,	71½
	Water,	73½
961	Air,	70
	Water,	74
1079	Air,	74
	Water,	74
1141½	Air,	74
	Water,	74
1200½	Air,	78
	Water,	78

Here the temperature (with some remarkable irregularities) augments by a descent of 1200 feet 28°, which is 1° for every 43 feet.

2. *United Mines—May*, 1819.

Depth in Feet.	Temperature.	
0	Air,	58°½
272¼	Air,	56
392	Air,	70
810	Air,	70
961	Air,	68
990½	Air,	73
	Water,	74

Here in a depth of 990½ feet the temperature augmented 15°½, or 1° for every 64 feet of depth. The anomalies are striking. The temperature at 272¼ feet deep is less by 2° than at the surface; while in the next 120 feet it augments by 12°. In the next 418 feet there is only an augmentation of 2°, and in the next 150 feet there is a diminution of 2°; the temperature at 392 feet being 2° higher than at 961 feet.

3. *Dolcoath Mine—October*, 1815.

Depth in Feet.	Temper. of Air.	
0		62°
420		62½
951		70
1020		71
1079		71·5
1171		74
1230		74
1381	Air,	80
	Water,	82

Here in a depth of 1381 feet the temperature increases 18°, or 1° for every 77 of descent. The same anomalies are observable as in the last mine. For the first 420 feet there is only an increase of temperature amounting to half a degree; while for the next 531 feet there is an increase of 9°½.

4. *Tincroft Mine—May,* 1819.

Depth in Feet.		Temperature of Air.
167¼		53°
331¼		52
439½		54
553½		56
659¼		62
767½	Air,	62
	Water,	59

Here a descent of 600 feet occasioned an augmentation of 9° of temperature, or 1° for every 66⅔ feet. The same kind of anomalies are perceptible. But this mine had been recently overflowed with water.

5. *Cook's Kitchen—May,* 1819.

Depth in Feet.		Temperature of Air.
167½		50°
298½		55
420		57
553½		57
639½		62
767½		63½
882⅓		64
1020		69
1121¾	Air,	69
	Water,	68

Here a depth of 954 feet occasioned an augmentation of the temperature amounting to 19°, or 1° for every 50 feet of descent. Similar irregularities occur here as in the other Cornish mines. This mine also had been recently inundated.

II. Mr. Bald made a similar set of observations on various coal mines in the north of England. The following tables exhibit the results which he obtained:*—

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* Edin. Phil. Jour. i. 134.

1. *Whitehaven Coal Mine, Cumberland.*

	Temperature.
Air at the surface,	55°
A spring at the surface,	49
Water at the depth of 480 feet,	60
Air at same depth,	63
Air at depth of 600 feet,	66

Here at a depth of 480 feet the temperature augments 11°, or 1° for 43 feet of descent.

2. *Workington Coal Mine, Cumberland.*

Air at surface,	56°
Spring at surface,	48
Water at depth of 180 feet,	50
Ditto at 504 feet depth,	60

Here the augmentation of temperature in a descent of 504 feet is 12°, or 1° for 42 feet.

3. *Teen Colliery, Durham.*

Air at pit bottom 444 feet deep in a country little elevated above the sea,	68°
Water at same depth,	61
Water at surface,	49

Here the depth of 444 feet produced an increase of temperature amounting to 12°, or 1° for every 37 feet of descent.

4. *Percy Main Colliery, Northumberland.*

Air at surface,	42°
Water about 900 feet below the bed of the sea, under the Tyne,	68
Air at same depth,	70
Water at surface,	49

Here a depth of 900 feet occasioned an augmentation of temperature of 19°, or 1° per every 47 feet of descent.

5. *Jarrow Colliery, Durham.*

Air at surface,	49°½
Water 882 feet below the surface,	68
Air at same depth,	70
Water at surface,	49

Here the elevation of temperature for a descent of 882 feet was 19°, or 1° for every 46 feet.

6. *Killingworth Colliery, Northumberland.*

	Temperature.
Air at surface,	48°
Air at pit bottom, 790 feet deep,	51
Air at depth of 900 feet, after having traversed 1¼ mile from the bottom to the downcast pit,	70
Water at depth of 1200 feet,	74
Air at same depth,	77
Water at surface,	49

Here the elevation of temperature for a descent of 1200 feet is 25°, or 1° for every 48 feet. This is the deepest coal mine in Great Britain.

7. *Princes-end Pit, Tipton, Staffordshire.*

Water at bottom of engine, pit above 400 feet deep,	47°½
Air in the mine,	60

8. A very satisfactory set of experiments was made on this subject at Sunderland, by Mr. John Phillips, in the month of November, 1834. Mr. Pemberton was engaged in sinking a pit at Monk-Wearmouth to reach the coal beds that lie under the magnesian limestone. It had been sunk to the depth of 1500 feet, and had passed through a bed of coal six feet thick. No attempt had been made to work this coal. The pit had been tubbed in various parts to stop the water, which nevertheless drops, but not in great quantity, down the sides. This water fills several yards below the coal bed in which the observations were made, to the bottom of the pit, which is to be carried considerably deeper to a lower bed of coal. The temperature of the air at the surface was 49°; that of the coal bed at the depth of 250 fathoms varying from 70°·1 to 72°·6.[*]

III. M. Humboldt, while in America, made some observations on the temperatures of mines in Mexico and Peru, the most important of which are exhibited in the following tables:[†]

1. *Mines of Mexico.*

Guanaxuato, lat. 21° 0′ 15″; height of the table-land above the sea, 7,034 feet; mean temperature of the air, 61°. The mine of Valenciana is so hot that in the deepest parts the

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[*] Phil. Mag. (third series), v. 446.

[†] Ann. de Chim. et de Phys. xiii. 207.

miners are constantly exposed to a temperature of 91°½. In the month of September the external air was 66°¾.

Between Despacho del tiro nueyo, and Bovedo de San Pablo, between 124½ and 249 feet deep, the temperature is 74°⅖ to 81°⅔.

In the plains of San Bernardo, at the depth of 747 feet, 92°⅘.

The temperature of the water at that depth, 98°¼.

Mine of Royas, not far from that of Valenciana, temperature of external air, 69°½.

At the depth of 286 feet, 92°⅔.

In the mines of Villapando, three leagues to the north of Guanaxuato, on a table-land 8,505 feet high, the temperature of the external air was 72°⅓.

At the depth of 199 feet, 85.

There are hot springs in the neighbourhood issuing from a basaltic conglomerata. Those of Comagillas have a temperature of 205°.

Mine of Cabrera, lat. 20° 10′ 4″ at a height of 1,512 feet. The temperature of the air was from 50° to 53°¼ (mean temperature of the place nearly 61°). In the gallery of Conde de Regla, at 74·7 feet in transition porphyry, the temperature was 70°.

Water at the same depth, 62°¾.

2. *Peru.*

Hualgayac, 6° 43′ 38″ South latitude, is a mine situated in an isolated mountain 13,429 feet above the level of the sea.

The thermometer stood in the air at	42°
In the gallery of the mine, . .	57 ¾
Water of the mine, . . .	52

In the mine del Purgatorio, which is exceedingly dry, the air is 67°¼.

IV. The following observations were made by Daubuisson in some of the Saxon mines during the year 1802:—*

1. *Mine of Beschertgluch*, 2 *leagues north of Freyberg.*

Depth in feet.	Temperature of air.
590 . .	52°⅕
853 . .	59

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[*] Jour. des Mines, xi. 517.

Here a depth of 263 feet occasioned an elevation of temperature amounting to 6°·8, or 1° for 38½ feet.

2. *Alte Hoffnung Gottes, near the same place.*

Depth in feet.	Temperature of air.
239½	48°
557½	55
885½	59
1246½	65⅔

Here a descent of 1007 feet occasioned an elevation of 17°⅔, or 1° for every 57 feet. The anomalies are of the same kind as in the Cornish mines. A descent from 239 to 557 feet, or 318 feet occasioned a rise of 7°; while for the next 328 feet the rise was only 4°; and for the last 361 feet the rise was 6°⅔, or nearly corresponding with the first 318 feet.

V. To the same observer we are indebted, in 1806, for the following facts respecting the temperature of some mines in Bretagne:—*

1. *Poullaouen, N. lat.* 48° 17′ 49″. *About* 853 *feet above the surface of the sea. Mean temperature* 52°·7—*September,* 1806.

Temperature of the external air, 66°.

Depth in feet.	Temperature.
52½	Water, 55°½
128	Do. 53½
246	Do. 53½
462½	59
492	Water, 56⅓ Air, 58

Here a descent from 128 to 492, or 364 feet, occasioned a rise of 2°⅔, or 1° for every 157 feet of descent.

2. *Huelgoat, lat.* 48° 18′ 11″. 567½ *feet above the surface of the sea. Mean temperature* 52—*5th September,* 1806.

Depth in feet.	Temperature of water.
49	52°
229½	54
262½	59
459	62½
754½	67½

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* Jour. des Mines, xxi. 218.

Here a depth of 754$\frac{1}{2}$ feet occasioned an elevation of temperature amounting to 15°$\frac{1}{2}$, or 1° for every 48 feet.

VI. The following observations on the temperature of certain coal mines in the south of France, were made by M. Cordier :—*

1. *Carmeaux, departmemt of Tarn.*

Depth in feet.	Temperature.
20$\frac{1}{5}$	55°$\frac{1}{5}$
37·75	55 $\frac{2}{5}$
596·66	62 ·75
629·75	67

Here a depth of 609 feet occasioned an elevation of 12°, or 1° for every 50 feet of descent.

2. *Littry department of Calvados.*

Temperature of external air, . . 52°
Do. of mine at 324·75 feet deep, 61

3. *Decises, department of Nievre.*

Depth in feet.	Temperature.
28·9	52 ·5
55$\frac{1}{5}$	53
351	64
551	70

VII. The following observations were made by M. Gerhard in 1829, on the temperatures of the bottoms of a variety of mines in Prussia, between N. latitude 50° and 51°$\frac{1}{2}$. The observations were continued for more than a year. The table exhibits the depth of the mine in feet, the mean height of the thermometer, and the variation observed in that height. The numbers in the first column refer to the table in page 11, where the names of the mines are given and the mean height of the thermometer, at from 27 to 67 feet below the surface. Most of these mines are at an elevation of from 500 to 3000 feet above the level of the sea, which accounts for the lowness of the temperatures observed :—†

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* Ann. des Mines (2d series), ii. 62.

† Poggendorf's Annalen, xxii. 497.

	Depth of mine in feet.	Mean height of thermom.	Variation of do.
1	164·54	46°·85	0
2	342·93	51 ·89	2°·25
3	169·37	49 ·7	0
4	154·64	50 ·47	1 ·125
5	394·37	48 ·81	0 ·56
6	478·72	56 ·75	0
7	400	49 ·66	2 ·25
8	480·1	50 ·43	1 ·125
9	230·13	50 ·58	2 ·25
10	376·05	47 ·59	0 ·28
11	280·41	48 ·13	1 ·128
	533·35	49 ·86	0
	786·4	58 ·1	2 ·25

When we compare this table with that in page 11, we perceive that the temperature, in every case, is higher at the bottom of the mine than near the top; though the same anomalies occur as in the observations of preceding geologists. The last which gives the mean height of the thermometer at three different depths in the coal mine near Herzogenrath, shows an elevation of 10° in a descent of 759 feet, or 1° of elevation for every 76 feet of deepening.

VIII. The following observations were made by Kupfer,* in the copper mine of Bagoslowsk, Eastern Russia, in North latitude 60°, and East longitude 60° 9′ 20″:—

Depth in feet.	Temperature of water.
183·7	38°
213·3	39 ·2
363·5	43 ·25

Here, a depth of 179·8 feet occasioned an increase of temperature of 5°·25, or 1 for every 34 feet of depth.

IX. At Charlieshope, New Jersey, Mr. Griffith observed the temperature of a spring 250 feet below the surface of the earth, to be 52°, and that of another 294 feet below the surface, to be 54°.†

X. The following observations by M. Spasky, show the temperature of the Artesian wells at Vienna, at different depths:—

* Poggendorf's Annalen, xv. 170. † Ann. des Mines (2d series), vi. 443

Depth in Vienna feet.	Temperature of well.	Depth in Vienna feet.	Temperature of well.
138	53°·15	150	55°·6
150	54 ·5	90	52 ·7
240	57 ·2	166	53 ·37
78	52 ·9	48	54 ·5
234	56 ·75	63	54 ·5
90	52 ·25	60	54 ·3
108	52 ·9	96	55 ·2
108	52 ·9	60	54 ·3
108	52 ·25	144	52 ·9
90	55 ·6	108	52 ·9
102	52 ·9	189	55 ·2
114	52 ·7	102	54 ·95
90	52 ·25	60	54 ·95
		162	54 ·5

The mean temperature of the air at Vienna is 50°·45. M. Spasky has calculated from the preceding observations, joined with the quantity of water given out by each well, that there is a mean augmentation of 1° of temperature for every 37·77 Vienna feet of depression below the surface.*

XI. The following observations were made by Erman, Magnus, and Schmidt, in a shaft which has been sunk in a limestone rock at Rüdersdorf, about twenty miles north-west from Berlin, to a depth of 880 German feet. The observations were made chiefly with a thermometer contrived by M. Magnus for the purpose, during the years 1831, 1832, and 1833:†

Depth in German feet.	Temperature.
80	55°·4
200	56 ·4
225	60 ·375
280	63 ·5
330	63 ·725
380	64 ·4
430	64 ·625
480	65 ·75
530	67 ·325
580	68
630	68 ·45
680	69 ·35
736	71 ·8
830	72 ·5
880	74 ·3

* Poggendorf's Annalen, xxxi. 365. † Ibid. xxii. 136; and xxviii. 233.

The preceding tables contain all the observations on the temperature of mines hitherto published, or at least which have come to my knowledge. With a few insignificant exceptions which can be easily accounted for, they show that the temperature rises as we sink deeper into the earth. But there is a very great difference in the rate of this increase in different mines. It may be worth while to collect this rate as deduced from the different mines observed.

1.	Huel Abraham	1° for	43 feet
2.	United mines	1	64
3.	Dolcoath	1	77
4.	Tincroft	1	66⅔
5.	Cook's Kitchen	1	50
6.	Whitehaven	1	43
7.	Workington	1	42
8.	Teen	1	37
9.	Percy main	1	47
10.	Jarrow	1	46
11.	Killingworth	1	48
12.	Beschertgluch	1	38·5
13.	Hoffnung Gottes	1	57
14.	Poullaouen	1	157
15.	Huel goat	1	48
16.	Carmeaux	1	50
17.	Littry	1	36
18.	Decises	1	30
19.	Herzogenrath	1	76
20.	Bagoslowsk	1	34
21.	Charlieshope	1	22

The difference is enormous. In the mine of Decises there is an elevation of 1° for every 30 feet of descent; while in Poullaouen an elevation of 1° requires a descent of 157 feet, or more than 5 times as great. If we were to leave out Poullaouen and Charlieshope as deviating too much from the rest, and take the mean of all the others, we would obtain nearly an increase of 1° for every 50 feet of descent.

Can this augmentation of temperature in mines be accounted for by any accidental causes, such as the burning of candles, the blasting of gunpowder, or the number of workmen employed in the mine? Dr. Forbes has given us the requisite data to determine these points in the mine of Dolcoath.*

In the year 1819 the number of men employed in that mine was 800, of whom a third part or 266 were always in the mine. The candles burnt amounted to 200 lbs. every day. The gunpowder employed in blasting the rock in which the mine is situated amounted to 86$\frac{2}{3}$ lbs. per day.

Now, the quantity of water pumped daily out of Dolcoath mine was 535,173 gallons, or nearly 4$\frac{1}{2}$ millions of pounds; and this water had the temperature of 84°, or was 33° higher than the mean temperature of Redruth, where the mine is situated: thus the heat carried off daily, in the water pumped out of the mine, would have heated 824,000 lbs. of water from the freezing to the boiling point.

From the facts ascertained respecting animal heat we have reason to conclude that the heat given out daily by 266 men would be sufficient to raise the temperature of the whole water from the mine one degree.

200 lbs. of candles, according to the best experiments on the heat evolved during the burning of tallow would be only sufficient to raise the temperature of the water of the mine 0·7 of a degree.

The heat from the explosion of 86$\frac{2}{3}$ lbs. of gunpowder would not raise the temperature of the water so much as $\frac{1}{10}$th of a degree.

Thus it is clear that all the heat from these adventitious causes does not amount to so much as $\frac{1}{13}$th of the 33 degrees of heat which the water contains above the mean temperature of Redruth, which must be very nearly 51°.

The simplest explanation of this curious fact, and the one which seems at present almost universally adopted, is, that the temperature of the central parts, of the globe is much higher than that of the surface; so high indeed as to be in a state of intense ignition. From this central ignited nucleus, the temperature gradually diminishes as we approach the circumference, where it is of course lowest: hence the obvious reason why the temperature so constantly increases as the depth of a mine increases. This explanation was advanced by Buffon and by other geologists many years ago. It was strenuously supported by Dr. James Hutton in his *Theory of the Earth*, first published in the *Edinburgh Transac-*

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* Transactions of the Geological Society of Cornwall, vol. ii.

tions about the year 1790, and afterwards in a separate form in 1795. The publication of this theory occasioned a violent controversy, which at last subsided, and many of the opinions of Hutton have been generally adopted by modern geologists.

If we admit the truth of this hypothesis, and consider the mean temperature at the surface to be 56°, since the temperature augments 1° for every 50 feet it is obvious that the temperature of the centre of the globe must be almost 418,000°.

This hypothesis would enable us to account in a very simple way for the hot springs which issue in such abundance in different parts of the globe. The temperature of a spring must depend upon the depth from which it rises. Were a spring to rise from the bottom of Dolcoath mine, which is 1,381 feet deep, to the surface, its temperature would be 84°, or 33° higher than the mean temperature of the place. Now, this happens to be the temperature of Buxton hot well in Derbyshire. We have only to suppose that the water fills a cavity 1,381 feet below the surface, and that from this cavity it rises in a natural pipe to the surface, to be able to account for the temperature.

The temperature of the hottest of the Bath springs is 117°, while that of the air is 50°; so that the Bath spring is 67° higher than the mean heat of the place. If we allow an increase of 1° for every 50 feet of descent, it is obvious that Bath water must form an accumulation in a cavity situated 3,350 feet below the surface of the earth. This amounts to 558 fathoms, which is much deeper than any mine, at least in Great Britain.

But though this supposition of a central fire be so simple and satisfactory that it has been generally adopted, it must not be concealed that there are several circumstances which rather militate against it.

1. It is sufficiently obvious, and has been already noticed, that the temperature of a place, *ceteris paribus*, is regulated by the latitude. The mean temperature of the equator is 81°·5; that of latitude 45° is 56°; that of Stockholm in N. lat. 60° is 41°; and that of Lapland in N. lat. 67° is 32°. In the temperate and frigid zones the mean temperature of summer is much higher than that of winter. This will be evident from the following table taken from that given in page 7:—

Places.	Latitude.	Mean Winter Temp.	Mean Sum. Temp.
Madeira, . .	32° 37′	63°·5	72°·28
Italy, . . .	40 50	50	77
France, . .	43 30	44 ·6	75 ·2
France, . .	47 10	41	68
England, . .	53 30	37 ·8	62 ·6
Scotland, . .	57	36 ·14	56 ·48
Sweden, . .	60 30	24 ·8	60 ·8
Gulf of Bothnia, .	62 5	16 ·7	59
Norway, . .	71	23 ·9	44 ·7

It is obvious from this table that in all these places the higher the sun is elevated above the horizon, and the longer it continues above the horizon, the higher is the temperature; and that in winter, when his altitude is low, and the days short, the temperature is much lower. From all this it cannot be doubted that the temperature is regulated entirely by the sun. Now, how could this be the case if there existed a central fire which makes its influence be felt so much as to raise the temperature 33° at a depth of 200 fathoms under the surface? It has been said, indeed, that the heat lost by radiation is just equal to that transmitted from the centre, so that the surface cannot be heated by the central fire, but only by the sun. But whatever effect may be ascribed to radiation, surely it must act equably on every part of the surface of the earth. But the poles are 12 miles nearer the centre than the equator is. Now, if every 50 feet of descent occasion an increase of 1°, 12 miles should occasion an increase of 1291°; so that allowing the heat dissipated from the surface by radiation to be equal at the poles and equator, still there ought to be an increase of more than 1200° of heat at the pole, derived from the central fire; so that the temperature at the pole, instead of —13°, ought to be enormously high. The low temperature of the pole, owing to the long absence of the sun, and probably also the absence of land, seems to me totally irreconcileable with the existence of a central fire in the globe, or at least with the notion that this central fire transmits heat to the surface in such quantity as to affect the thermometer.

2. The observations of Mr. Moyle, which were made during a series of years in Cornwall, seem to show that the high temperature of the mines in that county continues only while they are working.* When these mines are abandoned they

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* Annals of Philosophy (second series), iii. 308, 415.

get filled with water, which of course remains stagnant, and the temperature gradually sinks till it approaches that of the mean temperature of the place. The Oatfield engine shaft, at the depth of 182 fathoms, had a temperature of 77° while the mine was working. Mr. Moyle examined the temperature at that depth a few months after the mine had been abandoned and found it reduced to 66°. He tried it again many months after, and found the temperature reduced to 54°. Thus the temperature at the bottom of this mine had sunk after it was abandoned no less than 23°. It is obvious that if the original high temperature had been derived from the central fire, the mere abandonment of the mine could not have reduced it.

Mr. Moyle found the temperature in the abandoned mines of Herland and Huel Alfred, that of the former 54°, and of the latter 56°, and this at all depths. The working of these two mines being resumed, the water was drawn off, and Mr. Moyle examined it during the operation to the depth of 100 fathoms without finding any increase of temperature.

Huel Trenoweth is another example which Mr. Moyle has brought forward. It is 100 fathoms east of Crenver and Oatfield mines, on the same *load*. This mine was discontinued working for more than 12 months, at least as far as regards the presence of miners; but the engine was still kept working to relieve the other two mines. The adit at which the water is discharged is 32 fathoms from the surface. Here its temperature was 54°; and it gradually increased from this place to the mouth of the pump, where it was 56°. 15 fathoms deeper the walls of the shaft were 54°. A gallery at this level, 40 fathoms east of the shaft, was only 53°. 5 fathoms deeper, or 52 from the surface, where there is a second cistern of water, the water was 57°; the walls in the same place were 54°½. At the bottom, in 66 fathoms, the water that ran through a small crevice, as well as the walls of the shaft, were still 54°. The temperature of the air before going down was 68°, after returning 64°. Here it is obvious that there was no increase of temperature for 34 fathoms, being precisely the same at the bottom as at the adit shaft.

The following table exhibits the whole of Mr. Moyle's observations.* They show in the clearest point of view that the elevation of temperature is chiefly confined to mines at work, and disappears when they are abandoned:—

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* Annals of Philosophy (second series), v. 34.

Feet.		MINES AT WORK.												ABANDONED MINES.													
		Huel Unity.		Creeg-brawn.		Huel Trumpet.		Oatfield.		Cronver.		Huel Abraham.		Huel Tre-noweth.		Huel Pool.	Huel Rose.	Relis-tian.	Herland shaft.			Huel Alfred.	Huel Ann.	Treven-nan.		Huel Fanchise.	Huel Nancy.
		Air.	Wat	Air.	Wat.	Air.	Wat.	Air.	Wat.	Air.	Wat.	Air.	Wat.	Air.	Wat.				1	2	3			Air.	Wat		
60 to	120	—	Not working spots.	55°	51°	—	56°	—	—	All not at	spots work.	—	—	—	—	53	53½	—	—	—	—	56	52	—	—	—	—
120	150	54		60	—	—	Not working spots.	—	—			—	—	—	—	53	53½	55	—	—	—	56	52	53¼	52	51	51
150	200	—		—	—	—		61°	—	—	—	—	—	54°	—	—	—	55	54	56	52	56	—	—	—	51	51
200	250	—	—	—	—	—		—	—	—	—	—	—	54	53°	—	53½	55	54	56	52	—	—	—	—	—	—
250	300	—	—	62	—	58°	54	—	—	55°	—	—	—	54	—	—	—	55	—	—	—	56	52	—	—	—	—
300	350	62	54°	—	—	—	—	—	—	56	—	—	—	—	—	—	53	55	54	56	52	—	52	—	—	—	—
350	400	—	—	—	—	—	—	—	—	60	60°	—	—	54	—	—	—	—	54	—	—	—	—	—	—	—	—
400	450	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
450	500	—	—	—	—	—	52	—	—	61	61	—	—	—	—	—	—	—	—	—	—	—	52	—	—	—	—
500	550	—	—	—	—	67	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	56	—	—	—	—	—
550	600	—	—	—	—	68	53	—	—	62	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
600	650	71	69	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	54	56	52	—	—	—	—	—	—
650	700	—	—	—	—	—	—	—	—	64	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
700	750	—	—	—	—	—	—	—	—	64	60	—	—	—	—	—	—	—	—	—	—	56	52	—	—	—	—
750	800	—	—	—	—	—	—	—	—	63	61	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
800	850	—	—	—	—	—	—	—	—	64	62	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
850	900	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
900	950	74	65	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
950	1000	—	—	—	—	—	—	—	—	—	—	—	—	58	—	—	—	—	—	—	—	—	—	—	—	—	—
1000	1150	—	—	—	—	—	—	—	—	—	—	—	—	58	—	—	—	—	54	—	—	—	—	—	—	—	—
1150	1250	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1250	1300	—	—	—	—	—	—	78	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1300	1350	—	—	—	—	—	—	81	78°	—	—	85°	84°	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1350	1400	—	—	—	—	—	—	80	—	—	—	90	86	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1400	1450	—	—	—	—	—	—	85	—	—	—	84	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

These facts seem to me to leave no doubt that the increase of temperature observed in mines as we descend, cannot be owing to the heat communicated from the central parts of the earth; for, if it were so derived it could not disappear when the workmen left it, or when stagnant water was allowed to accumulate in it.

If it were merely the air in the mine, or even the surface of its walls which augmented in temperature, there would be little difficulty in accounting for the phenomenon. The number of miners usually present in the mine at one time (often amounting to 400), together with the heat from the candles and gunpowder exploded, might easily be supposed to increase the temperature very considerably, and this temperature would naturally increase somewhat as the mine deepened, in consequence of the greater density of the air; but we have seen that these causes are utterly inadequate to account for the augmented temperature of the vast quantity of water which is daily pumped out of these mines.

But to whatever cause we are to ascribe this augmented temperature, the facts above stated are incompatible with the notion that it is owing to a central fire.

3. That an intense state of ignition exists within the bowels of the earth, or at least at very considerable depths below the surface, is evident from the numerous volcanoes, more than 200 of which, in a state of activity, are known to exist on the globe. If we consider the evident connexion which many of these volcanoes have with each other, we shall be satisfied that the igneous energy to which they are owing is of the most extensive kind. The Andes extend from the island of Terra del Fuego to the table-land of Mexico, about 77° of latitude, or more than 5000 miles; or, if we exclude Terra del Fuego and Patagonia, as the existence of volcanoes in these districts rests upon uncertain evidence, the volcanic chain of the Andes extends over a space not less in length than 4700 miles, or 68° of latitude. Over the whole of this long space it is rare to find a degree of latitude in which there does not exist an active volcano. The internal fire, of which these craters constitute the vents, must be enormous in point of magnitude, and must exist at a very considerable depth below the surface of the earth, even without reckoning the Andes, which have been probably originally elevated by the expansive force of this internal fire.

A volcanic band, of very great extent, exists also in the

Indian Archipelago. It begins to the north of the Philippines in about 20° N. latitude, and extends south to Timor, in about S. latitude 10°; then proceeds west and north to the extremity of Sumatra, from East longitude 130° to 95°.

In Europe volcanoes exist in the Grecian islands, in Italy and Sicily, and in Iceland. Whether these volcanoes have any connexion with each other at a great depth is uncertain, no evidence of any such connexion being known. But if earthquakes and volcanoes both owe their existence to the same internal fires, then there is evidence that such an internal fire must exist at an enormous depth, and that it must extend over a very large space; for the earthquake which destroyed Lisbon in November, 1755, extended over a space which was not less than 4000 miles in length, and as much in breadth. It was felt in Pennsylvania and New York, at Antigua, in Madeira, in Barbary, in the North of Scotland, at Hamburg, and in many other places, though the centre of action seems to have been situated below the Atlantic, and north-west from Lisbon. Now, if an extensive volcanic fire exists under Europe, as is not unlikely from the facts just stated, it is possible that the temperature of some of the mines specified in the preceding pages may have been affected by this internal fire, which may very well be conceived to be nearer the surface of the earth in one place than in others: hence, perhaps, the reason why in some places it breaks out into active volcanoes, while in others it produces only earthquakes. Even if the temperature of mines should not be admitted to be affected by these internal volcanic fires, there can be little doubt that the hot springs which issue so abundantly in many parts of the earth owe their temperature to this cause.

CHAP. II.

OF THE SURFACE OF THE EARTH.

It is known to every person that the surface of the globe is partly *dry land* and partly water, and that nearly two-thirds of the whole is covered by the ocean. The proportion of land upon the north side of the equator is about 13 times as great as upon the south side. Hence the reason why in high southern latitudes the summers are colder and the winters milder than in the corresponding latitudes in the northern hemisphere.

The land is usually divided into five great continents; three of these exist in the eastern hemisphere, namely, Europe, Asia and Africa. A fourth, America, constitutes a great belt crossing the western hemisphere, from 68° North latitude to 56° South latitude, or above 8,500 miles in length. The fifth, denominated Polynesia, consists of New Holland and the neighbouring islands. The relative extent of these continents in square miles, may be stated as follows:—

	Square miles.
Europe, with its islands, .	2,243,000
Africa, with Madagascar, .	7,464,000
Asia, ...	11,039,000
America, ...	10,000,000
Polynesia, ...	2,745,000
	33,491,000

If we reckon the ocean at double the extent of the land, the whole surface of the globe will constitute about 100,000,000 square miles.

America constitutes two continents, North and South, the relative sizes of which are:—

	Square miles.
North America, Greenland, &c.,	5,803,000
South America, . . .	4,196,000

The dry land consists of *high* country, that is mountains and hills with elevated valleys between them; and of *low* country, or the extensive plains which lie at the foot of the mountains. The sea has also its plains, mountains, and valleys. Alpine country sometimes descends to the sea by a succession of valleys below one another, sometimes by one large plain. Elevated and extensive plains with opposite declivities do not terminate in one another, but are almost always divided by land of a mountainous character.

Single detached mountains are generally volcanic, or at least composed of *trap* rocks, which have exactly the aspect of lava. At Edinburgh there occur four such mountains, namely, Arthur's Seat, Salisbury Craigs, the Castle Hill, and the Calton. All of these are precipitous to the west, and slope gently towards the east. They are composed of greenstone, claystone porphyry, traptuff, &c. Near Stirling there are three exactly similar hills; namely, the Abbey Craig, the Castle

Hill, and Craigforth, besides some smaller ones of the same kind in the King's Park.

Mountains are generally found in elevated bands, consisting either of one central chain with branches running at right angles, or of several chains or ridges running parallel to each other. And in both cases frequently accompanied by subordinate or dependent chains of smaller elevation. The Alps, for example, consist of a great central chain extending in breadth between fifty and sixty miles. On each side of this chain there is a valley, and beyond these valleys a lower chain, which runs on each side parallel to the great central one. The Grampians exhibit a similar arrangement at least on the south-east side.

Mountain chains in general have a great length compared to their breadth. This is well exemplified in the Andes, which traverse South America from the isthmus of Darien to the Straits of Magellan, constituting a length of upwards of 4000 miles, while the breadth in general is under 100 miles.

If we consider the old continent attentively we shall find that its general form, the declivity of its surface, and the course of its rivers are determined by a great zone, which traverses it from one extremity to the other at a mean latitude of 40°. Mount Atlas, which bounds Barbary on the south, and traverses the north of Africa, between North latitude 30° and 32°, may be considered as part of this great mountain zone. The different mountain tracts in Spain, running in the same direction belong to the same zone. Under the name of the Pyrennees it separates France from Spain. A little farther east it assumes the name of the Alps. Mount Hemus connects the Alps with the great Asiatic chain, which under the names Taurus, Caucasus, Elbourz, is continued eastwards to the 70th degree of longitude. Here it divides into two branches; one of which, the Himalaya range, takes a south-easterly direction, and terminates about 500 miles to the north of the gulf of Bengal. The other branch called the Altai and Yablounoi, passes north-eastwards till it reaches the Pacific Ocean, in North latitude 55°. The entire length of this mountain zone, from west to east, is about 8000 miles, and its breadth varies from 500 to 2000 miles. The Sierras of Spain, the high ridge of Corsica and Sardinia, the Appenines continued through Italy and Sicily, and the mountains of Southern Greece, form so many transverse branches connecting together the great northern and southern chains of the band. The Carpathians in Hungary, and the Erzegebirge in Germany, may be considered as dependent chains of the Alps.

It is along this great zone that the highest eminences of the old continent occur. The Peak of Teneriffe is 11,022 feet above the level of the sea. Mont Perdu, long reckoned the highest of the Pyrenees, is 11,172 feet, by the measurement of M. Reboul; that of the other principal summits of the Pyrenees, by the measurement of the same gentleman, are as follows:—

Pic du Midi,	9,560½ feet.	
Canigou,	8,544	
Maladetta,	11,427¾	the highest of the Pyrenees.
Posets, .	11,280¾	

Mount Etna, which constitutes the most magnificent object in Sicily, is 10,955 feet above the surface of the Mediterranean, while Vesuvius, near Naples, is only 3,938 feet high. Mont Blanc, the highest of the Alps, and the loftiest of European mountains, is 15,665 feet above the level of the sea; and Mont Rosa, its rival in size and celebrity, is only 125 feet lower.

The highest mountain in France, Mount Pelvoux, is the summit of the mountains of L'Oisans,* in Dauphiné. It is 13,468 feet above the level of the sea, according to the measurement of Durand and Leclerc.* The Dole, constituting the highest peak of Mount Jura, is 5,577 feet above the level of the sea. Mount Meyen, in the Velay, is 5,900 feet high. The following table shows the height of the highest mountains in Auvergne, as determined by M. Ramond:—†

Puy de Dome, . .	4,846 feet
Petit Puy de Dome, .	4,189
Puy de Pariou, . .	4,012½
Puy de Vache, . .	3,894
Grand Sarcouy, . .	3,793

The Carpathian mountains, which separate Poland and Hungary, may be considered as a kind of continuation of the Alps, though there is a valley interposed between them. The great Lomnitzerspitze, the highest of these mountains, is 8,464 feet above the level of the sea, which is not much more

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[*] These mountains are composed of granite. An interesting Geological account of them, by M. Elie de Beaumond, will be found in the Annales des Mines (third series), v. iii.

[†] Jour. des Mines, xxiv. 241.

than half the elevation of Mont Blanc. The most westerly of these mountains is called Fatra. It runs north and south, and is divided into two by the river Waag. The following are the heights of its principal peaks, as determined by Wahlenberg:[*]

Coch,	5,196 English feet.
Krivan,	5,648
Klukberg,	4,442
Czerny-kamen,	4,583

To the eastern part of the Carpathian mountains the inhabitants give the name of Trata *(hideous)*, from its singular and dreary aspect. The following is the height of its principal peaks, as determined by Wahlenberg:—[†]

Krivan,	8,034 English feet.
Nod Pavlova,	5,942
Nochstein,	4,984
Viszoka,	8,313
The lake Hinzka,	6,219
Csabi,	8,313
Gerlsdorfkessel,	7,780
Great Lomnitzerspitze,	8,464
Hunsdorferspitze,	8,313
Rotheseethurm,	7,673
Hintere Leithen,	6,591
Stirnberg,	6,287

The height of Mount Hemus, or the Balkan, which constitutes the chain to the north of European Turkey, is not so well ascertained, though there are reasons for believing that it rises, in some places at least, to a height not inferior to that of the highest of the Carpathians.

Mount Athos, at the extremity of a peninsula in Macedonia, is one of the highest mountains in Greece. Its height, as measured by Captain Gauttier, is 6,778 feet. The following table exhibits the height of different mountains in the Grecian Archipelago, as determined by the same observer:—[‡]

Mount Kerki, isle of Samos,	4,793 feet.
Mount Jupiter, isle of Naxos,	3,328
Mount Olympus, Meteline,	3,241
Mount Christo, Stancho,	2,828
Mount Cochila, Skiros,	2,588
——— St. Elias, Milo,	2,559
——— St. Elias, Paros,	2,516

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[*] Annals of Philosophy, ix. 141.

[†] Ibid. p. 142.

[‡] Ann. de Chim. et de Phys., xviii. 433.

The height of Kasibeck in the Caucasus, according to Sir Robert Ker Porter, is 14,400; that of Elborus, in the same chain, is 16,414 feet;* while that of Mount Ararat, according to M. Parrot of Dorfat, who ascended it in 1829, is 17,266⅓ feet. The limit of perpetual snow on that mountain is at the height of 12,790 feet. Thus both Ararat and Elborus considerably exceed the height of Mont Blanc.

But this mountain zone reaches by far the greatest elevation towards its eastern extremity, in the extensive table-land of Thibet and the Himalaya mountains, which constitute the northern boundary of Hindostan. The Dologer, the highest of these mountains, rises to the enormous height of 27,677 feet, or 5¼ miles above the level of the sea; Javahir, the second in height, is 25,745; and Yamunatri, the third, 25,000 above the sea level.

The Altai chain has been partly examined by Humboldt, but he has not yet laid the result of his measurements before the public. Its height above the surrounding country is not very great, but it stands upon a very elevated base, and the extreme rigour of the climate shows that the absolute elevation above the level of the sea must be very considerable. The height of the little Altai above the level of the sea is, according to Laxman, 6,988 feet.†

Many very high mountains occur in the Asiatic Archipelago. Thus, in Sumatra we have

Gunong-Dempo,	12,000 feet.
Berapi, . .	13,003

and in the Phillippines, Ternate, 4,093 feet above the level of the sea.

Besides this central system of mountains there are two other ranges in the Old Continent upon the north side, and nearly at right angles to the central chain. These are the Uralian mountains between Europe and Asia, and long celebrated for the numerous mines that are wrought in them by the Russians, and the Doffrines which separate Sweden from Norway.

The Uralian mountains extend from about North latitude 54° to 66°, and run north and south not far from East longitude 60°. They constitute three parallel chains with valleys between them, the westernmost of which is the most

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* As determined by the late Russian Survey, by M. Zenz. See Ann. de Chim. et de Phys., xlii. 105.

† Ann. de Chim. et de Phys., iii. 309.

elevated. The highest mountain in that chain is Jeremel, which rises beyond the limit of perpetual snow, which in that latitude is about 5,500 feet above the level of the sea. Taganai, the next highest mountain in that chain, is, by Kupffer's measurement, 3,480 feet high. Slatoust, in the same range, is 1,193 feet, and Nasimskisch 2,216 feet. The second chain, called Ural, is lower; the height of it when passed on the way to Slatoust, is 2,059 feet; while Miask is 995·4 feet above the level of the sea. The farthest east chain is the lowest of all.*

The Doffrines extend in length at least 1000 miles. Indeed, if we were to consider the Grampians in Scotland, and the Irish mountains as a continuation of the Doffrines, their length would exceed 2,000 miles. The highest of these mountains is Sneehaetta, which, by the measurement of Esmark, is 8,120 feet above the level of the sea. The summit of this mountain was considered as inaccessible till it was reached by Esmark, and his journey is still celebrated in Norway as a most wonderful and dangerous exploit. Syllfjells, in latitude 63°, which Hisinger measured, is 5,819 feet above the level of the sea. Tronfjels, the next in elevation, is 5,611 feet. The snow line at the latitude of these mountains is 5,275 feet above the level of the sea, yet Hisinger found no snow upon the top of either of them in the month of August; this he ascribes to their pointed form, which prevents the snow from lying. It is to this form probably that the want of glaciers in these mountains is owing.

Beerenberg, in the isle of Mayen, near Greenland, is, by Scoreby's measurement, 6,840 feet above the level of the sea. It appears from his observations that the mountain is volcanic. The following table exhibits the heights of some of the principal mountains of Iceland:—

	English feet.
Hecla, . . .	5,110†
Eyafiäll, . .	5,679†
Oeräsa Jockal, .	5,927‡

The mountains in Scotland are less elevated than those of Norway. The Grampian mountains rise low a few miles to the south of Aberdeen, and proceeding in a south-west direction terminate in the table-land constituting the Mull of Kin-

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* Kupffer, Poggendorf's Annalen, xvii. 497.

† As measured by M. M. Ohlsen and Vetlesen.

‡ As measured by M. Paulson. See Poggendorf's Annalen, x. 19.

tyre. By far the highest tract of mountainous country in Scotland is that part of the Grampians called Brae Mar, at the west end of Aberdeenshire, whence the river Dee takes its rise. The highest mountain of that district is Beni Macdui, which, by the measurement of Dr. Skene Keith, is 4,300 feet; but by the measurement of the gentlemen who conducted the Trigonometrical Survey of Great Britain, 4,400 feet above the level of the sea. There are seven or eight mountains within a short distance of Beni Macdui not much inferior to it in height. Bennevis, in Inverness-shire, near the western extremity of the Caledonian canal, has an elevation of 4,370 feet, and has usually passed for the highest mountain in Great Britain.

Ben Lawers, in Perthshire, rising from the north side of Loch Tay, and the summit of which is almost a ridge, is 4,051 feet above the level of the sea. Benlomond, though so conspicuous from its situation at the western extremity of the flat district constituting the valley of the Forth, is only 3,262 feet high. The highest mountain in the south of Scotland is Hartfell, near Moffat, which, according to Dr. Walker's measurement, is 3,304 feet above the level of the sea. Helvellyn, in Cumberland, is about the same height. The highest mountain in England is Crossfell, in Cumberland, which is 3,390 feet above the level of the sea. Its eastern acclivity is so gentle that you may easily ride to its summit, but its western side, overlooking the Vale of Westmoreland, is very steep. Snowden, in Caernarvonshire, the highest mountain in Wales, is 3,568 feet high. Cader Idris, in Merionethshire, is only 18 feet lower.

Upon the north side of the great central chain, which may be considered as the spine of the ancient continent, there is an enormous plain, extending, with but little interruption, from the Atlantic to the Pacific Ocean. It occupies the space between the fiftieth and seventieth degrees of North latitude, having an average breadth of about 1,400 and a length of about 6000 miles. It embraces the north of France, England Holland and Belgium; the north of Germany, Denmark, Sweden and Russia.

On the south side, if we consider the Atlas range as connected with the great central chain, we have an immense zone of sandy deserts, 900 miles broad and 4,500 miles long, extending between the parallels of 18° and 31° north, and between the west coast of Africa and the mouth of the Persian Gulf, including Northern Africa, Arabia, Persia and the country to the north-west of Hindostan. This tract contains many mountains and some fertile valleys, but is characterized by vast desert plains, formed of very light moveable sands which assume the form of waves—by burning and pestilential winds—by an extraordinary aridity and want of rivers, and by an abundant formation of salt, sometimes deposited like a crust on the surface, sometimes mixed with the inferior soil.

The city of Gondar, in Abyssinia, in North latitude about 11°, and to the south of this sandy zone, is 8,440 feet above the level of the sea.

The heights of the mountains in the vicinity of the Cape of Good Hope, are as follows:—

Table mountain, . .	3,600 feet.
Devil's mount, . .	3,360
Lion's head, . . .	2,200
Lion's rump, . . .	1,100*

The new world forms two great continents united by a neck of high land. South America consists of one vast expanse of surface of small elevation, everywhere protected on the west by the great ramparts of the Andes. These mountains which run from south to north, at the distance of from 50 to 150 miles from the sea, constitute from 14° to 20° South latitude, two parallel chains divided by an elevated valley. Mr. Pentland in his geological tour in South America, measured some of the highest peaks of the Andes. The following are some of the most remarkable of these:—†

1. *In the Oriental Range.*

Nevado de Sorata, . .	25,250 English feet.

This is the highest peak probably of the Andes, and little inferior to Javahir, which is 25,745.

Nevado de Illimani, .	24,000 English feet.
Cerro de Potosi, . .	16,037

2. *In the Western Range.*

Tacora, or Chipicani, .	18,808
Pichu-Pichu, . .	18,603
Volcano of Arequipa, .	18,373
Inchocajo, . . .	17,192

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* Webster's Narrative, vol. i. p. 293.

† See Ann. de Chim. et de Phys. xlii. 435.

3. *Passages of the two Ranges.*

Altos de los Huessos, .	13,573 English feet.
Tolapalca, . . .	14,075
Gualillas, . . .	14,830
Paquani, . . .	15,227
Chullunguani, . .	15,610
Altos de Toledo, . .	15,692

4. *Cities in Peru and Bolivia.*

Lima, ...	512
Arequipa, . . .	7,799
Cochabamba, . . .	8,448
Chuquisacaor la Plata, .	9,331
Tupisa, . . .	10,003
La Paz, . . .	12,195
Oruro, ...	12,441
Puno, ...	12,832
Chucuito, . . .	13,025
Potosi, . . .	13,668

The height of Chimborazo, erroneously considered the highest of the Andes, is by the old measurements 21,440 feet above the level of the sea.

The highest mountain in Hermit island at Cape Horn, is 2,156 feet above the level of the sea.*

South Shetland appears to be volcanic. The highest mountains observed in it are in Trinity land, between South latitude 63° and 64°. They are between 6000 and 7000 feet above the level of the sea.†

There are three transition ridges proceeding eastward, and spreading out into a range of table-land as they approach the eastern coast. The northernmost of these is in Caraccas, at the latitude of 8° or 9° north. The second divides Guiana from the basin of the Amazons. The third proceeds from the Cordilleras, in South latitude 18°, and is the one which chiefly spreads out into a table-land. The low region of this continent is divided into three great plains, which form the basins of the three principal rivers, the Orinoco, the Amazons, and the Plata. In the basin of the Orinoco, the eye is fatigued by the unvaried aspect of a boundless level, uniform as the surface of the ocean; without a plant or any other object, much above a foot in height, to break its monotony. Except

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* Webster's Narrative, vol. i. p. 186.

† Ibid. p. 185.

on the borders of the rivers, these plains are destitute of trees. After the annual rains they are clothed with a luxuriant herbage, which disappears during the dry season. The Pampas of La Plata, which extend from 18° to 40° South latitude, are plains of the same description.

But the zone which divides the open plains and forms the basin of the Amazons, extending from 6° North to 18° South latitude, is one vast and continued forest. This middle region is the highest; but so low are all the three, that if the sea were to rise 50 fathoms at the mouth of the Oronoco and Plata, and 200 fathoms at the mouth of the Amazons, it would wash the foot of the Andes and submerge more than half of South America. The Llanas and Pampas are steppes, like those of Southern Russia. There are no real deserts in South America, except a narrow tract of rock and quicksands on the coast of Peru, between Coquimbo and Lima, on which no rain ever falls.

The Cordilleras do not traverse the isthmus of Darien. That isthmus, as we learn from the description of Mr. Lloyd, is hilly, the mountains generally running from north-east to south-west near Panama, and in other parts bearing a relation to, though not always parallel to, the line of coast. Their altitude was determined by Captain Foster, who found the highest of them to be rather under 2000 feet.*

The North American continent, like the South, is distinguished by one great chain of mountains, which traverse it from south to north nearly through its whole extent, leaving a large open level region to the east, and presenting a steeper and narrower declivity to the west. Mexico constitutes a high table-land from 7000 to 8000 feet above the level of the sea, and its mountains, which are chiefly volcanic, rise, some of them, to the height of 17,720 feet, or $3\frac{1}{2}$ miles above the level of the sea. This is the case with Pocatepetle, the highest of the Mexican mountains. The chain of the Rocky mountains ascends considerably above the level of perpetual snow. In latitude 46°, it seems to have an elevation of about 9000 feet. The highest mountain in that chain and the most elevated in North America, is Mount Elias, situated near the Pacific Ocean, in North latitude 60°. It is 18,090 feet above the level of the sea.

From the centre of Avatcha Bay in Behring's Straits,

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* Webster's Narrative, ii. 148.

(which divide Asia from America) five immense mountains are visible which rise insulated and steep above some lower eminences. Korazka, one of these mountains, is 11,468 feet above the level of the sea. It constantly emits columns of smoke from the northern side. Avatcharkaja, another of them, is an active volcano. Kluschefskaja, or Kamschatskaja, which is also a volcano, is 16,542 feet above the level of the sea.*

The Sandwich islands may be considered as a part of North America, at least they are much nearer that continent than the coast of Asia. They are nearly in the latitude of the tropic of Cancer, and about 15 degrees, or 955 miles west from the coast of California. They consist of a cluster of about a dozen of islands, some of which, particularly Owhyee, the largest of them, contain a number of very high mountains, all obviously volcanic. Merinoroa, the most elevated of these, is, according to Kotzebue's measurement, 15,874 feet above the level of the sea. Merinokoak, in the same island, rises to an elevation of 13,936 feet. Merinowororoi is 10,788 feet high; while the highest peak in Mowee, another of these islands, has an elevation of 10,683 feet.

These islands form a striking contrast with the numerous groups situated nearly south from the Sandwich islands and near the tropic of Capricorn, most of which seem to be nothing else than coral reefs, which at a comparatively recent period have emerged above the surface of the sea.

St. Helena is a volcanic island, situated nearly half way between Africa and America, and in about 16° South latitude. It is almost all high land, its mean height being 1,400 feet. The following table exhibits the height of its most remarkable mountains above the level of the sea:—†

Diana's peak, . .	2,697 feet.
Cuckold point, . .	2,677
Halley's mount, . .	2,460
Flagstaff hill, . .	2,272
Sandybay ridge, . .	2,200
Longwood, . .	1,730
Lot, . . .	1,444
Lot's wife, . . .	1,423
Ladderhill, . . .	600

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* Russian Voyage of Discovery, Annual Register, vol. lxxi. p. 544.

† Webster's Narrative, vol. i. p. 344.

Ascension island lies to the north-west of St. Helena in about 8° South latitude. Green Mount, the highest part of it is elevated 2,818 feet above the level of the sea.*

In a general point of view, the North American mountains determine the declivities of the soil and the course of the rivers, over nearly the whole continent. On the west side of the chain the slope is rapid, and the rivers, so far as they are known, flow directly to the Pacific Ocean, passing through a high broken interrupted chain which skirts the coast. On the east side they bend their course to the nearest sea, over a surface little inclined, flowing to the north-east and north in the northern parts, and to the south-east and south in the southern parts. On looking attentively at the rivers in the map of North America, it will be perceived that the chain of lakes above lake Erie, the upper Mississippi, the Missouri, the Arkansas, and the Red River, all point in one direction—to the south-east. But in consequence of the Alleganies, a chain of mountains which run north and south through the states of the Union, the St. Lawrence and the Mississippi after running nearly parallel, till within 500 miles of the coast, are suddenly deflected from their south-east course and proceed to the sea in directions almost exactly opposite.

The whole region east of the rocky mountains, from the 50th parallel to the Arctic Sea, is generally low, abounds in lakes, and is scantily wooded as far north as the 60th degree of latitude, beyond which trees cease to grow. From the Gulf of Mexico to the mouth of the copper mine river in latitude 67°, the country may be considered as one great plain, the summit of which, about the 50th parallel, is not probably more than 1,000 feet above the level of the sea. According to Humboldt, the mean height of the great basin of the Missouri is not more than between 500 and 800 feet.

The interior of the country between Mackenzie's River and Behring's Straits, and between Hudson's Bay and the coast of Labrador, is mostly unknown, except by Franklin's journey, who confined himself to the seacoast. The former is probably fertile and tolerably wooded, as the whole of the region west of the rocky mountains has a wild and humid climate. The discoveries of Parry and Franklin have shown that the northern limits of the American continent run generally between the 67th and the 68th parallel, and that the space between this

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* Webster's Narrative, vol. i. p. 388.

and latitude 78° or 80° is occupied by a group of islands, of which Greenland may be considered as a part.

The following table shows the height of some of the principal inhabited places of the globe, above the sea:—*

	English feet.		English feet.
Micuipam pa (Peru),	11,870	Clermont,	1,348
Quito,	9,341	Geneva,	1,220
Santa Fe de Bogota,	8,730	Freyberg,	1,220
Cuença (Prov. of Quito),	8,639	Ulm,	1,211
Mexico,	7,471	Ratisbonne,	1,188
Hospital of St. Gothard,	6,807	Moscow,	984
St. Veran (Marit. Alps),	6,693	Gotha,	935
Village of Breuil (Alps),	6,564	Turin,	755
Village of Heas (Pyrenees)	4,816	Dijon,	712
Gavarnie (Pyrenees),	4,738	Lanark,	660
Briançon,	4,267	Prague,	587
Barege,	4,232	Moffat,	582
St. Ildefonso (Spain),	3,789	Cassel,	518
Pontarlier,	2,693	Vienna,	512
Madrid,	1,971	Lyons,	508
Inspruck,	1,857	Milan,	420
Munich,	1,765	Bologna,	397
Berne,	1,758	Parma,	305
Lausanne,	1,663	Dresden,	295
Mine master's house at		Paris (Observatory),	239
Leadhills,	1,564	Dalkeith,	200
Augsburg,	1,558	Rome (Capital),	151
Saltzburg,	1,483	Wirtemberg,	144
Neufchatel,	1,437	Holyroodhouse,	135
Plombiers,	1,381	Berlin,	131

As all the parts of the ocean have a free communication with each other, and as it is a well known property of water to find its level when left to the free action of its own gravity, it is natural to expect that the mean surface of the ocean will in every part of the world be of the same level. But this apparently reasonable supposition has not been verified by observation. It was suspected by the ancients that the level of the Red Sea was higher than that of the Mediterranean. While the French army, under Bonaparte, was in Egypt, a committee of engineers, under the direction of M. le Pere,

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* Jour. de Mines, xxxviii. 202.

was appointed to measure the exact height of each, by levelling across the isthmus of Suez, which separates these two seas from each other. The result was, that the surface of the Mediterranean is 26·63 feet lower than the low water surface of the Red Sea.

In like manner it has been ascertained by Mr. Lloyd, who levelled across the isthmus of Darien, that the mean height of the Pacific Ocean at Panama, on the west coast of America, is 3·52 feet higher than that of the Atlantic at Chagres, on the east coast.* But, on the other hand, it has been inferred from the trigonometrical surveys made in France, that the surfaces of the Mediterranean and Atlantic are almost exactly on a level.

From the levels of the canals, which have been made from the west to the east coast of England, or at least from the Severn to the Thames,† it has been shown that the level of the Irish Sea and St. George's Channel, on the west coast of England, is higher than that of the German Ocean by no less than 74 feet.‡ Even in Scotland it is obvious from the Forth and Clyde Canal, that the level of the mouth of the Clyde at Bowling Bay is somewhat higher than the mouth of the Forth at Grangemouth; for, from the summit level to Bowling Bay, on the west side, there are 18 locks, while to the east end of the Canal the number of locks are 19. This makes the surface of the water at the mouth of the Clyde about 10 feet higher than at Grangemouth.

The difference between the level of the Black and Caspian Seas is still more remarkable. It had been suspected that the surface of the Caspian Sea is about 300 feet lower than that of the Black Sea. Messrs. Engelhardt and Parrot levelled the whole space between the two seas no less than three times successively. The result was that the surface of the Caspian is 324·72 feet lower than that of the Black Sea, which is nearly on a level with the Mediterranean. It is obvious from this that Astracan, and the plains both of Russia and Persia bordering on the Caspian, are at a considerably lower level than the ocean.

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* Phil. Trans. 1830, p. 59. The summit level of the isthmus of Darien is 633·32 feet above the sea.

† From the observations of Mr. Lloyd, it appears that the mean level of the Thames, at the London docks, is 2·0359 feet above the mean level of the sea. Phil. Trans. 1831, p. 189.

‡ Galton, Annals of Philosophy, ix. 177.

The Caspian is much less salt than the Mediterranean; indeed, it contains only ¼th of the usual saline contents of sea water. Engelhardt and Parrot are of opinion that the Caspian originally stood at as high a level as the ocean, and that its surface has gradually sunk 324 feet, and thus laid dry a vast tract of country originally covered with water.

From this very general view of the surface of the terrestrial portion of the globe, it is obvious that a great proportion of it consists of level plains, while the mountainous regions, though considerable in point of extent, are confined to particular chains. The level districts of the earth are either covered with soil or with sand, or with stratified rocks, while the mountainous regions consist of rocks partly stratified and partly unstratified. When we dig into the level parts of the globe, we come always to beds of rock regularly stratified and deposited one above another, often horizontally, sometimes in an inclined position, and sometimes standing almost, or quite vertical. These rocks are sometimes composed of sand agglutinated together; sometimes of clay; sometimes of limestone; and many of them abound with fossils, consisting chiefly of sea shells, but sometimes of vegetable impressions, and sometimes of the bones of amphibious animals, quadrupeds or birds.

From the regular way in which these different beds are laid upon each other, from the nature of the ingredients of which they are composed, and from the sea shells with which they are frequently mixed, it is evident that these strata have been deposited at the bottom of the sea, and afterwards elevated either by the subsidence of the ocean or the elevation of its bed. They must therefore have been washed down from the mountainous parts of the earth by the action of the rain and rivers. These mountains must have in the course of ages been carried into the ocean, and immersed under its surface. Some notion of the length of time that must have elapsed before such a transference could be accomplished may be formed from this, that ever since the commencement of history, or for a period of at least 3000 years, the surface of the earth has been pretty much in the same state as at present.

For example, St. Michael's Mount, in Cornwall, is a small hill about 500 yards south from the dry beach, over against Merazion. It is about 231 feet high. During low water it is attached to the main land, so that you can walk to it from Merazion; but at high water it is an island being on all sides surrounded by the sea. This little island has been exposed to a very boisterous sea, yet during almost two thousand years its size and distance from the land has been very little altered; for Diodorus Siculus, who wrote during the reign of Augustus, and therefore rather before the commencement of the Christian era, gives an account of it under the name of Iktis (ἰκτις). He informs us that it was an island adjoining to Britain; that during the recess of the tide the intervening space is left dry, but at full tide, this passage being overflowed, it becomes an island.* This description would apply accurately to St. Michael's Mount at this day. Had any considerable change happened to it in an interval of at least 1800 years, surely it would have become either an island or a peninsula. The description of all the mountains, and most of the countries of Europe left us by the ancients, would apply almost exactly to them at the present day. It is true that in some places the sea has encroached somewhat upon the land, while in others the land has encroached upon the sea; but the alterations, taken as a whole, are insignificant. Athos, a conspicuous mountain in Macedonia, and running into the sea, was described with some minuteness by the ancients, and was represented by them as the highest in Greece. They even inform us how far its shadow extended at a particular season of the year, from which a tolerable inference may be drawn respecting its height. Now, Captain Gauttier measured it barometrically, and found its elevation above the sea to be 6,763 feet, a height which rather exceeds that deduced from the observations of the ancients.

Another remarkable circumstance connected with the strata of which the external crust of the globe is composed, is, that no remains of man are ever found fossilized in them. The lowest beds of all contain no fossils whatever. The next set of beds contain both animal and vegetable remains: the animal remains are shells, not one of which is identical with any shells at present existing in the ocean or in lakes. The same remark applies to the fossil plants, which, though numerous, cannot be identified with any vegetable bodies at present existing. We ascend a considerable way in the series before we come to amphibious animals; but the skeletons of several of these, of enormous size, and differing from any at present existing, have been met with in these strata. Quad-

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* Diodorus, Book v.

rupeds* and birds never appear till we come to those beds which are situated above the chalk; and even in these beds not a single bone has been discovered which can be identified with that of any quadruped or bird at present existing. Higher up still in the series we meet with beds containing shells partly similar to those at present existing, and partly consisting of extinct species. The proportion of those recent fossil shells increases as we advance upwards in the series. But we do not arrive at beds containing no fossil remains, but of animals at present existing on the earth or in the sea, till we come to those beds which are at present forming by the action of the sea, or rivers, or by the filling up of lakes, and therefore called *alluvial.* The remains of man, so far as is known at present, are confined to these alluvial beds.

From the preceding statement it is evident that a vast number of years must have elapsed before the earth was brought into the state in which it is at present. What was its appearance when it came originally out of the hands of the Creator we have no data to determine. No doubt its surface was partly land and partly sea; and at least from the period when plants and land animals made their appearance on it, the surface must have been unequal, and consisted of mountains and valleys as at present, otherways rain and rivers, to which the original surface owed its destruction, could not have existed.

The vegetable remains met with in such abundance in the coal beds resemble most those plants which at present are confined to the torrid zone. The same remark applies to the bones of amphibious animals and quadrupeds which occur in such abundance in Siberia, North America, and in England. They constitute pretty frequently extinct species belonging to genera at present confined to the torrid zone. This circumstance has led to the opinion that the temperature of the temperate and frozen zones is at present much lower than it once was, and that this change of temperature may have been one of the causes of the extinction of many species of animals which now no longer exist.

Be that as it may, it is impossible to doubt that both the animals and vegetables belonging to this globe have undergone very considerable changes since the original creation. Not a single species of the aboriginal animals and vegetables

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* In the Stonefieldslate, however, which is a portion of the Oolite formation, fossil remains of a species of Didelphis have been found.

any longer exist. The earth may have contained an indefinite number both of animals and vegetables, which disappeared in succession during the course of a very long series of ages. But we can only reason from those animals and vegetables whose fossil remains still exist.

Now, if we attend to the different strata of which the crust of the earth is composed, placed as they are above one another, it is obvious that the lowest of these strata must have been first formed, and that the order of formation must be the order of position. Consequently the animal and vegetable fossils in the lowest beds must be the most ancient inhabitants of the earth of which we can ever attain any knowledge. When strata, however distant from each other, contain the same fossil remains, we must conclude that they were deposited either simultaneously, or at least while the earth was inhabited by the same species of animals and vegetables. When the fossil remains alter in their nature, and present new tribes of animals and vegetables, we are sure that the temperature or some other essential circumstance has altered, and that the strata were deposited at a different period. How great an interval of time elapsed between the deposition of these and the former strata we have no means of even conjecturing. The little alteration which has taken place during the 4000 or 5000 years which have elapsed since the beginning of history, warrants our concluding that the interval between two such periods must be very long. Such is the mode by which we are enabled to form some notion of the relative antiquity of the different beds constituting the crust of the earth. Let us now turn our attention to these different beds.

CHAP. III.

OF FORMATIONS.

When mineralogists first began to study the rocks, they observed that some of them contained the fossil remains of animals and vegetables, while others were quite destitute of any traces of such fossils. This induced Lehman, a German mineralogist, when he published his work *On the Strata of the Earth*, in 1759, to divide rocks into two classes, *primary* and *secondary*. The *primary* were those which contained no animal or vegetable remains; the *secondary*, those in which such remains existed, or at least those which alternated with strata containing such remains. This division has been attended to by all subsequent geologists, and may be considered as a first step towards a classification of rocks.

The primary and some of the secondary rocks were studied with great care by Saussure, who devoted the greatest part of his life to an examination and description of the Alps; and by Pallas, who, after much laborious travelling, drew up a geological account of the mountainous portion of the Russian empire.

But it is to Werner that geology is chiefly indebted for the high rank which it at present holds among the sciences. He was Professor of Mineralogy in the Mining Academy of Freyberg, in Saxony, and possessed an influence over the minds of his students that has seldom been equalled and never exceeded. He examined the structure of that part of Saxony where he resided, and determined the relative position of its different rocks. He then boldly generalized his observations, and affirmed that the structure of the whole earth was precisely similar to that portion of Saxony which he had examined. His pupils, actuated by an enthusiasm which nothing could damp, set about verifying the opinions of their master. Every corner of Europe was examined with that particular object in view. At first they scarcely ventured to differ from the dogmas of their teacher; yet knowledge accumulated prodigiously, and after the examination of the volcanic regions of the globe, which the Saxon professor had never had an opportunity of studying, some of the most fundamental positions of Werner were combated and rejected.

The regular distribution of the secondary rocks on every part of the earth's surface, was still maintained by the pupils of Werner. These secondary rocks or *formations* (as Werner had named them) were distinguished by appropriate names, derived from the nature of the rocks of which they were considered as composed; they were found in every part of Europe and America, and from the practice of giving the same name to rocks situated at a great distance from each other, and from considering them as having been deposited at the same time on every part of the earth where they occur, much confusion got into the descriptions, and geology was in danger of reverting again to a state of chaos and confusion; when Mr. William

Smith conceived the happy idea of verifying formations by the fossils which they contain, and of tracing the same formations by means of the identity of their fossils to great distances, and of determining this identity, even when the stony matter of which they were composed was entirely different.

Mr. Smith was a practical engineer in the neighbourhood of Bristol. The country round that city has been cut through in various directions, in consequence of the peculiar position of its coal beds. This made Mr. Smith well acquainted with the numerous rocks or formations in that interesting neighbourhood. The rocks round Bristol are full of animal remains, consisting chiefly of shells. It struck Mr. Smith as very remarkable, that every particular formation contained, and was distinguished by containing, particular species of shells not to be found in the other formations. He made a collection of these shells, and found, that by his knowledge of them, he could trace the particular formations to a great distance from Bristol. He generalized these observations, and concluded that every *formation* may be best distinguished by the petrifactions which it contains.

To verify this idea, he undertook a survey of England and the south of Scotland, and after an arduous labour of twenty years, produced his geological map of England, exhibiting the mineralogical structure of that kingdom.* It was this map which laid open the geology of England to the Geological Society of London, which had been formed a few years before. They have prosecuted the subject with an enthusiastic zeal and a liberality and perseverance, which does them infinite honour. Mr. Greenough, the original founder of the society, assisted by some of the most eminent of the Fellows, constructed a new geological map of England, in which the scientific names were introduced, and several corrections made upon the original map of Smith. Not satisfied with this, they have published a considerable number of volumes of Transactions, filled with original observations of the most valuable kind, in which they have thrown a new light, not only on the geology of England, but of every accessible part of the globe.

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* This map was published in the year 1815. But Mr. Smith was acquainted with the structure of a great part of England, and with the fossils peculiar to each bed, as early as the year 1799, if not earlier; for, during that year, he communicated his views on the subject to Mr. Townsend and various other geologists.

The errors of the Wernerian geology have been pointed out and expunged from the science, and the arrangement of the secondary rocks has been based upon the fossils which they contain, and not upon any supposed identity in their constituents.

The formations constituting the outer crust of the earth, so far as it has been penetrated, may be arranged under the following divisions; beginning with the uppermost and proceeding regularly in the order of position:—

1. Alluvial beds.
2. Diluvial.
3. Pliocene.
4. Miocene.
5. Eocene.
6. Chalk.
7. Green sand.
8. Oolite.
9. New red sandstone.
10. Coal beds.
11. Mountain limestone.
12. Old red sandstone and greywacke.
13. Clay slate and mica slate.
14. Gneiss.

Besides these, which, with their subdivisions, constitute the regular strata in the order of position, there occur other rocks, which seem to have forced themselves up through these regular strata, and either spread over them or insinuated themselves between them. These rocks are distinguished by the names of *granite*, *trap*, and *porphyry*. Several of these are peculiar, while others resemble the lavas from volcanoes. These it will be proper to consider, after having described the regular beds.

CHAP. IV.

OF ALLUVIAL AND DILUVIAL FORMATIONS.

In what state the earth came originally from the hands of the Creator, we have no means of knowing. Even supposing it to consist entirely of crystallized rocks, still there must have been part of the surface covered with water and part in the state of dry land as at present; and this dry land must have been distinguished by mountains and valleys, otherwise the economy of nature could not have been similar to what it has been since it was inhabited by man. We must admit that the vicissitudes of summer and winter, of rain and sunshine, followed each other as they do at this day. These wasting causes acted upon the mountains and rocks. The frosts in winter would loosen fragments of stone, which the rains and torrents would gradually carry to the low country, breaking them in their descent into smaller fragments, or to grains of sand. By this means the valleys and flat country would come gradually to be covered with soil, which is nothing else than rock comminuted or reduced to impalpable powder. Upon this soil vegetables would grow, and by their decay would naturally accumulate a matter fit to be employed as the food of plants. Animals would next make their appearance, after the earth became covered with a sufficient crop of plants to support them.

Now, this disintegration of rock, which must have commenced immediately after the creation of the earth, still continues and gives origin to various beds of clay, sand, gravel, pebbles, &c., which we occasionally meet with. The torrents which, after rain, run down the steep faces of the mountains, gradually wear deep ruts in them, and of course carry the fragments of rock removed from these places into the valley below. These fragments rubbing against each other are partly converted into powder and partly into rounded pebbles. The pebbles of course are soon deposited when the declivity begins to diminish; but the powder being light remains in suspension so long as the water continues to move rapidly. These streams, when they reach a lower level, naturally discharge their water into it, and thus form a lake. Here the water remaining stagnant, will deposit the mud with which it was impregnated, and make its escape at the farther extremity of the lake in a state of transparence and purity. If this process be allowed to go on long enough, the lake will be gradually filled up on all sides, except a channel through which the united streams will make their way in the form of a river. What constituted originally the bottom of the lake, will now be alluvial soil of greater or less thickness, and composed of an indefinite number of strata. These strata may be clay or sand, or loam, or gravel, &c., according to circumstances; or they may consist of alternations of these in every conceivable proportion. If the lake contained shell-fish, it is obvious that the remains of these shells will be mixed with the beds. If these shells be very numerous, they may convert the whole of the deposits into what in this country is usually called *marl*, and which is employed as a manure. Such is the case with the beds at the bottom of the lake Bakie in Forfarshire, described by Mr. Lyell.* Similar deposits of marl have been observed in different parts of Berwickshire.

In like manner it may be inferred from the appearances of the valleys of Sanquhar and Closeburn, in Dumfries-shire, that they were formerly lakes, which have been drained by the Nith forcing a passage at their lowest extremity, and thus carrying all their waters into the sea. Nor is it unlikely that the valley of the Annan, in the same county, was also at one time an extensive inland lake.† Humboldt is of opinion that the vast valley of the Mississippi and Missouri was at a remote period covered with water, but was drained by these rivers forcing a passage and carrying off the surface water into the Gulf of Mexico.

The Falls of Niagara furnish another remarkable example of a lake in the progress of draining. That river flows from Lake Erie to Lake Ontario; the former lake being 330 feet above the latter, and the distance between them being 32 miles. The river before reaching the falls is propelled with great rapidity, being a mile broad, about 25 feet deep, and having a descent of 50 feet in half a mile. It is precipitated over a ledge of hard limestone in horizontal strata, below which is a somewhat greater thickness of soft shale, which decays and crumbles away more rapidly, so that the limestone forms an overhanging mass projecting 40 feet or more above the hollow space below. The disintegration of the shale is constant, and the limestone falls occasionally in huge masses with a noise like that of an earthquake. The waters, which expand at the Falls, are contracted again after their union into a stream not more than 160 yards broad. The bed of the river below the falls is strewed over with huge fragments which have been hurled down into the abyss. By the continued destruction of the rocks, the Falls have, within the last 40 years, receded nearly 50 yards. Through this deep chasm the Niagara flows for about seven miles; and then the table-land, which is almost on a level with Lake Erie, suddenly sinks down at a place called Queenstown, and the river emerges into a plane which continues to the shores of Lake Ontario.

There seems good reason for believing that the Falls were once at Queenstown, and that they have gradually receded

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* Geological Trans. (second series), ii. 71.

† See Jameson's Mineralogical Description of the County of Dumfries, p. 22.

about seven miles. This at the rate of 50 yards in 40 years must have required a space of almost 10,000 years; and should the erosion go on at a similar rate, at least 30,000 years will elapse before they reach Lake Erie. When that time comes, Lake Erie, the depth of which does not exceed 12 fathoms, will be suddenly drained, and a tremendous deluge will be the result.

Another source of alluvial soil is the action of the sea upon its shores. When the shore is rocky, the continual dashing of the spray against the face of these rocks, and the corroding effects of air and moisture cause their constant disintegration. Huge blocks are loosened, and tumble into the sea below. These masses are violently dashed against each other, and against the rocky shore, when the sea is agitated by a tempest; thus their corners are rubbed off, and they are converted into rounded water-worn shingles, which are piled up against the rocky shore, and thus the sea in such places raises a barrier against itself. This action of the sea is very well seen on the rocky shore of Scotland from St. Abb's Head, the southern extremity of the Firth of Forth to Berwick-upon-Tweed. The rocks are partly greywacke, and partly greenstone, and basalt, and porphyry. The fantastical shapes into which they have been worn, and the immense collection of fragments at their feet, and within the limits of the sea, are not a little striking. Nor are the phenomena less striking, though the nature of the rocks is different from the Redhead, at the northern extremity of the Firth of Tay to the Bullers of Buchan, at the northern termination of Aberdeenshire. The village of Mathers, two miles south of Johnshaven, was built on an ancient shingle beach protected by a projecting ledge of limestone rock. This was quarried for lime to such an extent that the sea broke through, and in 1795 carried away the whole village in one night, and penetrated 150 yards inland, where it has maintained its ground ever since, the new village having been built farther inland upon a new shore.*

Even the chalk cliffs at Flamborough Head are perceptibly yielding to the destroying action of the sea. But the waste is much more rapid between that promontory and the Spurn Point. This tract consists chiefly of beds of clay, gravel, sand, and chalk rubble. The irregular mixture of the clay beds causes many springs to be thrown out, which facilitates

* Lyell's Geology, i. 302.

the undermining process. Apprehensions are entertained that before long the Spurn Point will become an island, and that the ocean entering into the estuary of the Humber will cause great devastations. For the devastations committed by the sea upon the coasts of Norfolk, Suffolk, and Kent, and the south of England, we refer the reader to Mr. Lyell, who has described them in detail, and in his usual interesting manner.*

Even in the estuary of the Forth, the sea has committed great devastations within the memory of many persons living. About forty years ago there was a road from Leith to Newhaven along the sea shore, between which and the sea there was a considerable beach. The whole of this beach, together with the road, was swept away by the sea in one winter. Even that part of the beach which lies between the battery and the sea, though protected by a stone wall raised at a great expense, has been repeatedly injured.

To these inroads of the sea, on various parts of the coast, we are to ascribe the submarine forests which have been observed in various places on the coast of England. A submarine forest on the coast of Lincoln was described many years ago by Correa de Serra.† A number of islands extending a considerable way along the coast were found to consist almost entirely of roots, trunks, branches, and leaves of trees and shrubs intermixed with some leaves of aquatic plants.

In 1832 Mr. Yates gave an account to the Geological Society of London of a submarine forest in Cardigan Bay. It extends along the coast of Merionethshire and Cardiganshire, being divided into two parts by the estuary of the river Dovey, which separates those counties. It is bounded on the land side by a sandy beach and a wall of shingles. Beyond this wall is a tract of bog and marsh formed by streams of water which ooze out through the sand and shingles. The remains of the forest are covered by a bed of peat, and are distinguished by an abundance of *Pholas candida* and *Teredo navalis.* Among the trees, of which the forest consisted, is the pinus sylvestris, or Scotch fir. The tradition is, that this forest was submerged in the year 520.

Mr. Charles Harris discovered evident traces of a fir wood

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* Lyell's Geology, i. 306, &c.

† Phil. Trans., 1799, p. 145.

beneath the mean level of the sea at Bournmouth, in Hampshire, the formation having been laid open during a low spring tide. It is situated between the beach and a bar of sand about 200 yards off, and extends 50 yards along the shore, cropping out from beneath the sand and shingle. The formation consists of a stratum of soft peat, in which are implanted several large stumps of fir from one to two feet in height, the roots and bases of which still retain their bark.*

Forests buried under the surface of the ground are met with occasionally at a distance from the sea. There is a remarkable example of this about four miles west from Newcastle-upon-Tyne, near the river. About five years ago a new road was made in that direction, and a field was dug through to the depth of about four feet. It was found to consist of a vast number of trees lying on their sides, and only a few feet below the surface. Many of the trees were almost fresh. The moss of Kincardine, about six miles west from Stirling, consists of a bed of peat from 8 to 12 feet thick. At the bottom of it are a vast number of trees which have been cut down, and lie usually with their tops turned eastwards. Even the hatchets with which the trees had been cut down are occasionally found in the moss. It has been supposed by some that this is the remains of the Caledonian forest which was cut down by Agricola.

It is exceedingly probable that forests either cut down on purpose or allowed to fall down from old age after they have ceased to vegetate, have given origin to many of the mosses which are found in such abundance in the temperate regions of the northern hemisphere; at least there are few mosses in Great Britain or Ireland in which the trunks of trees (especially pines) are not found. This is even the case in the mosses of Caithness; though at present that county is nearly destitute of wood, and though the proprietors have not been able to succeed in making trees to grow, at least to any height.

The trees, after falling, occasioned a quantity of water to stagnate round them, and thus converted the tract into a bog. In this bog different species of sphagnum naturally made their appearance. This moss has the property of decaying below, while a new crop vegetates on the surface; and in this way a considerable thickness of decayed vegetable matter was accumulated round the trees. This matter, from the combined

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* Lyell's Geology, ii. 274.

action of water and pressure, gradually assumed the nature of peat, so that the whole tract was converted into a moss.

Considerable tracts of alluvial land have been accumulated round the coast of Denmark, partly in the state of islands, and partly attached to the main land. Of the formation and history of these tracts, a very interesting account is given in the first volume of M. de Luc's *Geological Travels*, to which we refer the reader for much curious information respecting the way in which land is formed on the borders of the sea.

Besides these alluvial formations, there are others of a similar nature, but which, judging from the fossil remains which they contain, must have been formed at a time when the state of the earth was different from what it is now. These formations bear unequivocal marks of deriving their existence from the action of water. On that account they have been distinguished by Dr. Buckland, and most modern geologists, by the name of *diluvial* deposits.*

A very remarkable *diluvial* formation occurs under the town of Brighton, in Sussex, which has been very well described by Mr. Mantell.† Brighton is situated on an immense accumulation of water-worn materials, which fills up a valley or hollow in the chalk. It is enclosed in chalk on every side, except the south, where it is washed by the sea, forming a cliff, from 70 to 80 feet high. It is composed of broken fragments of chalk, with angular pieces of flint, imbedded in a calcareous mass, of a yellow colour, constituting a hard and coarse conglomerate. It is not stratified, but is merely a confused heap of alluvial materials. In the inferior portion of the mass the chalk is reduced to very small pieces, which gradually become large in proportion to their height in the cliff. At length fragments of flint appear, and these increase in size and number as they approach the upper part of the bed, of which they constitute the most considerable portion. These flints are more or less broken, and resemble those which have been long exposed to the atmosphere. It contains also water-worn blocks of siliceous sandstone, and ferruginous breccia. Thus, all its constituents are obviously derived from the rocks in the neighbourhood, which must have been forcibly broken and triturated by the violent action of water, though at present they are several hundred feet above the level of the

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* From the Latin word *diluvium*, which signifies *a flood*.

† Geology of the South East of England, p. 29.

sea; and before the upper portions of them were worn away they must undoubtedly have been considerably higher.

The organic remains discovered in this deposit are the bones and teeth of the ox, deer, horse, and of the Asiatic elephant. These occur but seldom, and are generally more or less water-worn; but in some instances they are quite entire, and cannot have been subject to the action of the waves. It is obvious from this, that this deposit (called by Mr. Mantell the *elephant bed*) must have been formed at a time when the south of England was inhabited at once by the Asiatic elephant, the ox, the deer, and the horse, and therefore at a time when the climate was milder than at present.

The city of Glasgow is built upon a thick bed of siliceous sand, composed of grains of quartz obviously water-worn. To the north and west of the city there are low hills composed of clay, interspersed with fragments of other rocks, most commonly clayslate, greenstone and sandstone, though I have met with a few fragments of granite and porphyry. These fragments are often of the size of the human head, or even larger. They are all rounded, and obviously water-worn. The hill at the west end of the city is elevated at least 200 feet above the surface of the Clyde. This hill, called Blythswood hill, is composed of the same clay as the other hills in the neighbourhood. The sand is very similar in appearance to what constitutes at present the bed of the Clyde. We might therefore suppose that it had been formed in the course of ages by the action of that river, which might perhaps have repeatedly altered its course, and thus given birth to a pretty broad tract of sand. But the existence of Blythswood hill, and the hill to the north of the city, which consist of beds of sandstone, covered at the top by eight or ten feet of clay, could not well be ascribed to any such deviations of the course of the river. The sand and the clay can be observed in contact nowhere in the immediate neighbourhood of Glasgow; but at Dalmuir, about seven miles down the Clyde, the sand is seen very evidently overlying the clay. We may therefore conclude, from analogy, that at Glasgow the clay (constituting the rising grounds) is an older deposit than the sand.

But the remarkable circumstance, which throws back the formation of this deposit of sand to a very remote era, is, that it is traversed from east to west by two dykes or veins of greenstone, which probably hold a direction approaching to parallel, at a distance of about half a furlong from each other.

The farthest south of these dykes was cut through about 16 years ago, in making a common sewer in Virginia Street. The greenstone dyke was found to cross the street somewhere about the middle of its length. The other dyke was detected about 5 years ago, while digging the foundation of the Bank of Scotland, on the north side of Ingram Street, at the end of Glassford Street. About a year after, the same dyke was met with at the western extremity of College Street, while digging the foundation of the Chemistry laboratory and Class-room. This situation is a little to the north of the former. Hence, the dyke seems to run from east by north, to west by south. It was not possible to determine the thickness of these dykes, nor to examine their junction with the sand. They consisted of a hard small-grained greenstone, very similar to other rocks of the same formation in the neighbourhood. If these greenstone dykes were deposited after the formation of the sand, it is evident that the date of this diluvial deposit, upon which Glasgow is built, must be very remote.

The hill on the north side of the city of Glasgow, and upon which the oldest portion of the town is built, may be about 300 feet above the bed of the Clyde. It is a round-backed hill, running from west to east, and gradually sinking at both extremities. The under portion of this hill is composed of thick beds of coal sandstone, alternating with thin beds of slate clay and shale. The upper portion is a thick bed of strong blue clay, without any visible stratification. It is full of water-worn pebbles of different sizes; the largest, which consist of rounded blocks of greenstone and granite, are found towards the bottom; the smaller pebbles, of red and yellow sandstone, clay slate and quartz, are nearer the surface. These pebbles are all quite smooth, and those of greenstone and granite are often almost spherical.

No shells have been observed in the gravelly soil upon which Glasgow is built; but the same kind of bed may be traced a considerable way down the Clyde, and depôts of shells have been observed at Rothesay, Paisley and Roseneath. Near Dalmuir, in the parish of Old Kilpatrick, about 7 miles west from Glasgow, there occurs a bed of shells, at least 8 feet thick. This bed lies in the gravel, and constitutes a circular space about 4 yards in diameter. All the shells are recent, and most of them belong to species still existing in the sea on the west coast of Scotland. The following 29 species were picked up by my son in this bed, during about half an hour's examination on two separate days:—*

Echinite.

1. Echinus esculentus.

Shells.

1. Serpula,
2. Balanus scoticus,
3. Mya truncata,
4. Saxicava rugosa,
5. Amphidesma Boysii,
6. Tellina tenuis,
7. Lucina flexuosa,
8. Astarte minima,
9. Cyprina vulgaris,
10. Nucula minuta,
11. Cardium edule,
12. Anomia ephippium,
13. Mytilus edulis,
14. Modiola albicostata,
15. Pecten Islandicus,
16. Pecten pusio,
17. Patella parva,
18. Fissurella Noachina,
19. Velutina communis,
20. Helix lævigata,
21. Natica glaucinoides,
22. Littorina vulgaris,
23. Trochus cinerarius,
24. Lacuna vincta,
25. Rissoa,
26. Fusus Bamffius,
27. Fusus lamellosus,
28. Buccinum undatum,
29. Buccinum striatum.

These shells are all natives of the British sea, with the exception of the Fusus lamellosus, which has only been observed about the Straits of Magellan, and the natica glaucinoides, which is a crag fossil. But the most common shells in the neighbouring sea are the rarest at Dalmuir; while those found at Dalmuir in the greatest profusion are mostly rare in the sea. Thus of the Mya truncata, one of the commonest shells in the Firth of Clyde, only one imperfect specimen was found at Dalmuir; while the Fusus Bamffius, Lacuna vincta, Fissurella Noachina, and Astarte minima, none of which are common shells, together with Natica glaucinoides, a crag fossil, are very common at Dalmuir.

The carse of Stirling bears some resemblance to the alluvial formation round Glasgow. The uppermost bed of the carse is a stiff blue clay, containing numerous fragments of shells about a foot and a half below the surface, but so tender and so much broken that only two species have been made out; namely, the *cardium edule* and the *turbo littoreus*. There is a third species (perhaps a *tellina*), but so much broken that it cannot be determined with certainty. These shells are

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* See his paper in the Records of General Science, i. 131.

common in the Frith of Forth at this day. They show in the most unequivocal manner, that the whole carse has been covered by the sea since it has been inhabited by the same shell fish that live in it at present.

Below the clay lies a bed of sand of unknown thickness. The clay bed is thickest at the east end, and gradually thins out to the west. At Touch, about 3 miles west of Stirling, it is only a few inches thick. At the Castlehill of Stirling its thickness is 21 feet. Farther east than this I am not aware that the sand has been observed under the clay, though its existence may probably be inferred from analogy.

That part of Inverness-shire through which the Caledonian canal has been cut consists of a diluvial gravel of very considerable thickness. It is composed of water-worn pebbles, chiefly or entirely derived from the rocks in the neighbourhood.

The east coast of Sutherland from the Ord of Caithness to the Firth of Dornoch, a few spots excepted, consisted some years ago of a deep mould thickly mixed with rounded boulders of granite of all sizes, from several tons weight to the size of a pea. The late Duke of Sutherland improved a considerable portion of this tract at an immense expense, by trenching the whole and blasting the boulders, which were built up into walls by which the fields were divided.

Connected with these diluvial deposits are the immense masses of rock which have been carried to a great distance from the mountain masses whence they were taken, and deposited upon the surface. Thus the west coast of Ayrshire, in Scotland, is scattered thick with blocks of granite, obviously of the same kind as what constitutes the central Arran mountains. Now, between Arran and Ayrshire there is interposed a portion of sea, which in its narrowest part is twelve miles broad. It seems impossible to conceive that these blocks were transported through the sea. The transport must have taken place either at a time when Arran was joined to the mainland of Scotland, or when the coast of Ayr was sunk under the sea, and at least as deep as any part of the sea between it and Arran.

At Crieff, in Perthshire, there occurs a series of low hills running parallel to the Grampians. These hills consist of old red sandstone and greywacke. On one of them, the Cnock, the village of Crieff is built. Upon the south-east side of this hill, towards the southern extremity, not far from the summit, there are deposited a number of boulder stones of syenitic granite. The largest of these is called the *cradlestone*. It is nearly spherical, quite smooth on the surface, and 29 feet in circumference. It has been split in two by lightning, (according to the tradition of the place,) and one of the fragments has made one complete revolution down the hill and then stopped. The weight of this boulder is about 30 tons. The nearest mountains of syenitic granite, are those in the neighbourhood of Bennevis, distant more than 60 miles north-west, and between which and the Cnock, a considerable number of mountains are interposed, composed of porphyry, mica slate, and clay slate. It is impossible that such a block could have made its way to such a distance and over such obstacles. It is obvious, that when it was transported to Strathearn, the mountains at present interposed could not have existed.

Many similar boulders have been observed in the vales of Westmoreland and round the Solway Firth, and indeed in many parts of England.

Dr. Hibbert found fragments of rocks at Papa Stour, in the Shetland islands, which must have travelled twelve miles from Hillswickness. At Soulam Voe, open to the northern ocean, there are boulders three or four feet high, which do not correspond with any rocks in the country, and were probably derived from the northwards.

The vast number of erratic blocks of granite on the south side of the Baltic, and indeed scattered over the surface of Sweden and Russia, have been long known. All these correspond with the mountains on the north of Scandinavia and Russia. Count Razomouski informs us, that where many blocks are accumulated, they form parallel ranges with a direction from north-east to south-west. These blocks are very numerous between St. Petersburgh and Moscow, and are all composed of Scandinavian rocks. In some places, particularly in Esthonia, they appear and disappear at greater or smaller intervals, apparently owing to the form of the land at the time of their transport. They occur abundantly on the heights, and are but rarely and thinly scattered over the lowlands. Professor Pusch informs us, that the erratic blocks, from the Duna to the Niemen, are composed of granite resembling that of Wiborg in Finland, of another granite with Labrador felspar from Ingria, of a red quartzose sandstone from the shores of lake Onega, and of a transition limestone from Esthonia and Ingria.

In eastern Prussia, and in that part of Poland situated between the Vistula and the Niemen, the granitic blocks are abundant: three varieties of granite are the same as those found in Finland, at Abo, and Helsinförs: another coarse-grained granite and a syenite, are also from the north. The hornblende blocks of the same countries, are from southern and central Finland. The quartzose blocks are exactly the same as the rocks named Fjall Sandstein, between Sweden and Norway. While the porphyry blocks have the same character as the porphyries of Elfsdalen in Sweden. From Warsaw to the west, towards Kalish and Posen, the blocks of red granite of Finland diminish in number, but those composed of hornblende rocks and gneiss become more abundant, as is also the case with those of porphyry. Few Finland rocks are found there, while those of Sweden are common.*

Blocks of extraordinary magnitude have been observed at the foot of the Alps, and at a considerable height in some of the valleys of the Jura, exactly opposite the principal openings by which rivers descend from the Alps. These blocks are composed of the same materials as the rocks of the Alps, from which they must have proceeded. Many speculations have been indulged in to account for the transportation of these blocks, such as ice, torrents, the rising or subsidence of the mountains. But it seems unnecessary to enter upon such speculations, because nothing better than conjecture has been advanced in their support.

Another remarkable class of substances which have been considered as diluvial, are collections of bones accumulated in caverns. Geologists are obliged to Dr. Buckland for first turning their attention to this subject, and for contriving a theory, so ingenious and plausible, that it has been generally adopted. The cavern of Kirkdale, in Yorkshire, was discovered in 1821. Dr. Buckland visited it in the autumn of that year, and inserted a full account of the fossils found in it in the *Philosophical Transactions* for 1822. The cavern occurs in a bed of oolitic limestone, and is situated about 36 feet above the bed of the Hodge Beck. It lies on the north side of the valley of Pickering, in Yorkshire, distant about 25 miles from the city of York. The cave was accidentally opened by workmen while engaged in quarrying the rock.

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* Pusch, Jour. de Geologie, ii. 253, as quoted by De la Beche, Manual, p. 172.

It is a low zig-zag cave extending in length above 150 feet and from 2 to 7 feet in height. It is partly filled with stalactite and stalagmite, and the bottom contains a bed of mud, in which the bones are irregularly distributed. The bones are those of a *hyæna*,* similar to the species which occurs at the Cape of Good Hope, of the *bear (ursus spelæus)*, the *tiger*, the *fox*, the *wolf*, the *elephant*, the *rhinoceros*, the *hippopotamus*, the *ox*, a very large *deer*, various species of *deer*, the *water-rat*, the *rabbit*, the *mouse*, the *raven*, the *pigeon*, the *duck*, the *hog*. No complete skeleton of any of these animals occurred, but only detached bones. These bones were much worn down, or *gnawed*, as Dr. Buckland expresses it. And fragments of a substance like album græcum, which he considers as the excrement of hyænas, were also found. Dr. Buckland also mentions bones of the *horse* among those found in the cave; but Mr. Young assures us that these bones had been introduced by some persons in the neighbourhood with the malicious design of misleading the doctor in his researches. Dr. Buckland is of opinion, that at a very remote period when hyænas, and other tropical animals, were inhabitants of England, this cave was occupied as a den of hyænas. That these animals had dragged fragments of the carcasses of the larger quadrupeds into their den, and after devouring the flesh had left the bones. The smaller animals were dragged in altogether. The *flood*, he is opinion, surprised these animals in their den, but did not enter with such rapidity as not to permit them to escape. Hence the reason why no skeletons of hyænas have been found in this cave. The cave being filled with muddy water, this mud gradually subsided and enveloped the bones.

Such is the theory of Dr. Buckland respecting the bones in this cavern, and he has rendered it by his ingenuity exceedingly plausible. Even though we should hesitate about adopting his conclusion that the cavern was a hyæna's den, still it could scarcely be doubted from the phenomena that the cavern had been filled with turbid water, at a time when the animals, whose bones are found, inhabited England, and consequently when the climate was very different from what it is at present.

Caverns with similar deposits of bones and muddy matter

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* Of the bones found in such caverns about eleven-twelfths belong to carnivorous animals. Three-fourths are the bones of *bears*, one-sixth of *hyænas*, and the remaining one-twelfth, the bones of all the other animals.

are found in other parts of England. Thus three different caverns were met with in the limestone rock at Oreston in Catwater, near Plymouth, by the workmen while quarrying stones for the Plymouth breakwater. An account of these caverns by Mr. Whidbey has been published in the *Philosophical Transactions.*[*]

The bones found in the first cavern, discovered in 1816, belonged all to the rhinoceros. One cavern, found in 1820, contained bones and teeth of the bear; and another contiguous contained only bones of a deer or antelope. In the cavern discovered in 1822 were found the bones of the ox, the deer, the horse, the hyæna, the wolf and the fox. These caverns communicated with each other, and the bones of the herbivorous animals were found huddled together, but those of the carnivorous at a distance from each other: those of the hyæna being in one cavity, and those of the wolf and fox in another. Some of these bones were partially covered with stalagmite, but most of them were merely imbedded in a stiff clay which filled the bottom of the caverns. From the trials of Mr. Clift it appeared that these bones had been deprived of almost all their cartilaginous matter, which was not the case with those in the Kirkdale cavern.

Banwell cave, in the Mendip hills, was found to contain bones of the bear, cat, deer, ox, and some other animals. Similar caverns have been met with at Torquay, and in different parts of Wales.

The German caverns of Gailenreuth, Küloch, Bauman, &c. contain an abundance of bones, nearly identical, according to Cuvier, over a space of 200 leagues, by far the greater proportion being referrible to two extinct species of bear, *Ursus spelæus* and *Ursus arctoideus.* The remainder consist of the extinct *hyæna* (the same as in the Kirkdale cave), a *felis*, a *glutton*, a *wolf*, a *fox* and *polecat.* In these caves there is more or less of a stalagmitic crust, beneath which the bones are discovered, the stalagmitic matter being frequently transfused through the previously deposed sediment. They contain occasionally also some water-worn pebbles.

I think it unnecessary to describe similar caverns which have been met with in various parts of France; nor the osseous breccias of Italy, Sardinia, Gibraltar, Corsica, and other places on the shores of the Mediterranean.

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[*] Phil. Trans., 1823, p. 78.

But it may be worth while to notice a similar cave discovered in New South Wales, and described by Major Mitchell. The principal ossiferous cavity is situated near a large cave in Wellington valley, about 170 miles from Newcastle, through which valley flows the river Bell, one of the principal sources of the Macquarrie. The cavern is a wide and irregular well or fissure, accessible only by ladders or ropes, and the breccia is a mixture of limestone fragments of various sizes, and bones enveloped in an earthy red calcareous stone. The bones have been referred to the *kangaroo*, *wombat*, *dasyurus*, *koala* and *phalangista*, all animals at present existing in New Holland. But bones also of the elephant have been met with in it, and in another cavern bones of a kangaroo, exceeding by one-third the largest known species of that genus.

Dr. Bigsby has described a cavern at Lanark, in Upper Canada. The floor is covered with the debris of a brown granular limestone, similar to that of the rock in which the cavern exists, forming, with the bones, a kind of breccia, similar to that in the cavern of Adelsberg.

In some of these ossiferous caverns in France, along with the bones there occur fragments of ancient pottery, and occasionally human bones, showing that at least a portion of these bones were deposited in the caverns after the country had been inhabited by man. In some of the Welsh caves human bones have been found, but from the way in which they are deposited there is reason to believe that they had been employed as burying places.

It is evident from these examples, and many more might have been adduced, that what have been called *diluvial deposits* are of very different ages, and that, like all the other beds constituting the crust of the earth, they owe their origin to the action of water. It would not be an easy matter to distinguish between alluvial and diluvial deposits; probably, in many cases there is no real distinction in the agents, excepting, perhaps, in their amount.

CHAP. V.

OF PLIOCENE FORMATIONS.

THE term *pliocene** has been contrived by Mr. Lyell, and applied to certain tertiary deposits distinguished by the great number of recent shells which they contain, but mixed with many species which no longer exist. These beds he subdivides into two groups, namely, *newer* pliocene, and *older* pliocene; the former containing a greater proportion of recent shells than the latter. The following table exhibits Mr. Lyell's arrangement of these strata:—

I. *Newer Pliocene.*

Character.	Localities.
Marine.	Strata of the Val di Noto, in Sicily, Ischia, Morea? Uddevalla.
Fresh water.	Valley of the Elsa, around Colle, in Tuscany.
Volcanic.	Older parts of Vesuvius, Etna and Ischia—volcanic rocks of the Val di Noto.

II. *Older Pliocene.*

Marine.	Northern sub-appenine formations, as at Parma, Asti, Sienna, Perpignan, Nice—English crag.
Fresh water.	Alternating with marine beds near the town of Sienna.
Volcanic.	Volcanoes of Tuscany and Campagna di Roma.

We shall treat of these two groups in their order.

I. *Newer Pliocene Formations.*

The most remarkable of these beds exists in the Island of Sicily. About two-thirds of this island are occupied by primary and secondary rocks, the remaining third is covered by tertiary formations, which are of great extent in the southern and central parts of the island.

The Val di Noto is a district which intervenes between Etna and the southern promontory of Sicily. A considerable tract of it, containing within it hills which are from 1000 to 2000 feet in height, entirely composed of limestone, marl, sandstone,

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* From πλειων, *greater*, and καινος, *new*.

and associated volcanic rocks, belongs to the newer pliocene era. These rising grounds of the Val di Noto are separated from the cone of Etna and the marine strata whereon it rests by the low flat plain of Catania, just elevated above the level of the sea, and watered by the Simeto. The whole series of its strata are divisible into three groups, exclusive of the associated volcanic rocks. The uppermost mass consists of limestone, which sometimes constitutes a bed 700 or 800 feet in thickness. Below this, but much inferior in thickness, the following beds occur in the order in which they are named:—

2. Calcareous sandstone.
3. Conglomerate.
4. Shistose limestone.
5. Blue marl.

The whole of these beds contain shells and zoophytes, nearly all of which are referrible to species now inhabiting the contiguous sea.

The uppermost, or *great limestone* bed, often resembles the yellowish-white building stone of Paris, well known by the name of *calcaire grossière*, or coarse limestone; but it often passes into a much more compact stone. In the valleys of Sortino and Pentalica it is in strata nearly horizontal, and very regular. It abounds in natural caverns. The shells in this limestone are often very indistinct, sometimes nothing but casts remaining; but in many localities, especially where there is a slight intermixture of volcanic sand, they are more entire, and can almost all be identified with recent Mediterranean testacea. Several species of pecten, particularly the *Jacobæus*, or large scallop, now so common on the coasts of Sicily, are very numerous. The following shells, at present found in the Mediterranean, have been figured by Mr. Lyell as occurring in this formation:—

Turbo rugosus,
Trochus majus,
Solarium variegatum,
Tornatella fasciata,
Pleurotoma vulpecula,
Buccinum prismaticum,
Cassidaria echinophora,
Cytherea exoleta.

A list of the other shells belonging to this formation will be found in M. Deshayes's tables of fossil shells, inserted at the end of the third volume of Lyell's *Geology*, to which the reader is referred.

The mineral characters of this great calcareous formation vary considerably in different parts of Sicily. In the south, near the town of Noto, the rock puts on the compactness, together with the spheroidal concretionary structure of some of the Italian travertins. At the same place it contains the leaves of plants and reeds. At Spaccaforno, and other places in the south of Sicily, a similar compact variety of limestone occurs, where it is for the most part pure white, often very thick, and without any lines of stratification. This hard white rock is often four or five hundred feet in thickness, and appears to contain no fossil shells. It has much the appearance of having been precipitated from the waters of mineral springs, such as frequently rise up from the bottom of the sea in the volcanic regions of the Mediterranean.

This great limestone passes downwards into a *white calcareous sand*, which has sometimes a tendency to an oolitic and pisolitic structure. At Florida, near Syracuse, it contains a sufficient number of small calcareous pebbles to constitute a conglomerate, where also beds of sandy limestone are associated, replete with numerous fragments of shells, and much resembling the English cornbrash. In some parts of the island this bed seems to be represented by yellow sand, like that superimposed on the blue shelly marl of the Subappenines in the Italian peninsula.

Under the preceding beds is found an argillaceous deposit of variable thickness, called *creta* in Sicily. It resembles the blue marl of the Subappenine hills, and like it, encloses fossil shells and corals in a beautiful state of preservation. A list of these shells will be found in Deshayes's table at the end of Lyell's Geology. Almost the whole of them are identical with shells at present existing in the Mediterranean.

This bed usually rests on an older series of white and blue marls, containing skeletons of fish interposed between the thin laminæ of the white marls.

The volcanic rocks associated with these beds, constitute a very prominent feature in the Val di Noto. These lavas sometimes lie under and sometimes over the stratified rocks. For we find dykes of lava intersecting both the marl and limestone, while in other places calcareous beds repose upon lava, and are unaltered at the point of contact. Thus the shelly limestone of Capo Santa Croce, rests in horizontal beds upon a mass of lava, which had evidently been long exposed to the action of the waves, so that the surface has been worn quite smooth. This limestone is unchanged at its junction, and encloses within it pebbles of lava.

The volcanic rock of the Val di Noto, usually consists of the most ordinary variety of basalt with or without olivine. It is sometimes compact, often very vesicular. The vesicles are either empty or filled with calcareous spar, arragonite, and zeolites. The structure is sometimes spheroidal and sometimes, though rarely, columnar.

The formation of these different pliocene rocks seems to have been a very slow process. Near Lentini, Mr. Lyell found some imbedded volcanic pebbles, covered with full grown serpulæ. At Vizzini, a bed of oysters, the same as our eatable species, and twenty feet thick is seen resting upon a current of basaltic lava. Upon the oyster bed is superimposed a second mass of lava, together with tuff and piperino. Near Galieri, a horizontal bed about a foot and a half thick, composed entirely of a common Mediterranean coral (*Caryophyllia cespitosa*) is seen in the midst of the same series of alternating igneous and aqueous formations. These corals stand erect as they grew, and after being traced for hundreds of yards, are again found at a corresponding height on the opposite side of the valley.*

Similar deposits of newer pliocene formations were observed by Mr. Lyell at the foot of Mount Etna. At the base of the cone there runs a low line of hills formed of clays and marls, associated with yellow sand, similar to the formation provincially termed *Creta* in different parts of Sicily. This marine formation, composed partly of volcanic and partly of sedimentary rocks, is seen to underlie the modern lavas of Etna. Its extent cannot be determined; but it contains the same shells and constitutes a similar formation with that in the Val di Noto already described.

The same formation exists on the east side of Etna and in the Cyclopian islands, in the larger of which it seems to have been heaved up and contorted by masses of columnar lava that lie under it. Mr. Lyell is of opinion, that the whole of Mount Etna, except what has been formed during the historical era, belongs to the newer pliocene formation. On the eastern side of the mountain there is a deep valley called Val del Bove, where the structure of the mountain may be studied. It is a vast amphitheatre four or five miles in diameter, surrounded by vertical precipices, varying from 1000 to above 3000 feet in height. Here a great multitude of vertical dykes may be seen in all directions traversing the volcanic

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* Lyell's Geology, iii. 62.

beds, which all dip towards the sea. Some of those dykes are compact trachyte, others consist of blue basalt with olivine. They vary in breadth from 2 to 20 feet and upwards, and usually project from the face of the cliff. They consist of harder materials than the strata which they cut, and therefore waste away less rapidly. They obviously consist of lava currents which made their way through rents in the older lavas.

Mr. Lyell is of opinion, that these newer pliocene beds were gradually deposited at the bottom of the sea by aqueous attrition from the rocks, &c., on the contiguous land, that there they were mixed with the shells which existed in the Mediterranean at the time of their deposition; and that they were gradually and slowly hardened and elevated by volcanic energy. He has produced a great many proofs, that the sea coast in many parts of Italy has been raised within the historical era. One of the most remarkable of these examples, is the temple of Serapis at Puzzuoli. The base when built, must have been above the level of the sea. Afterwards it sunk below that level, as is obvious from the columns, to the height of 20 feet being perforated by Lithodomous shells. Finally, it must have been again elevated at least as high as when originally built.*

Mr. Lyell has pointed out the existence of similar newer pliocene formations in Campania, at Conception bay in Chili, the parallel roads of Coquimbo in the same country, at Honduras, Madeira, and in several other localities.

Several fresh water formations of the same period are also enumerated by him, as the valley of Elsa in Tuscany, between Florence and Sienna, where we meet with fresh water marls and travertins† full of shells, belonging to species which now live in the lakes and rivers of Italy. Valleys several hundred feet deep have been excavated through the lacustrine beds, and the ancient town of Colle stands on a hill composed of them. The travertins and calcareous tufas which cap the hills at Rome, may belong to the same period. The terrestrial shells enclosed in these masses, are of the same species as

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* Lyell's Geology, i. 517.

† The term *travertin* is applied by the Italians to a limestone deposited from the water of springs holding lime in solution. The Germans give to the same substance the name of *kalktuff*. The Italian word is a corruption of the term *Tiburtinus*, the stone being formed in great quantity by the river Anio at Tiber, near Rome, and hence it was called by the ancients *Lapis Tiburtinus*.

those now abounding in the gardens of Rome; and the accompanying aquatic shells are such as are found in the streams and lakes of the Campagna. On Mount Aventine, the Vatican, and the Capitol, we find abundance of vegetable matter, principally reeds encrusted with calcareous tufa, and intermixed with volcanic sand and pumice.*

Several fresh water breccias belonging to the same period occur in Sicily. Thus, for example, caves occur in the newest pliocene limestone of the Val di Noto, containing a breccia in which bones of extinct species of the elephant and hippopotamus occur. Similar caves are met with near Palermo. Mr. Lyell assigns the erratic blocks of the Alps to the same period.

In the pliocene formations there occur about 55 species of plants. Of these 27 belong to recent species, 22 are confervæ, 5 are palmæ. The remaining 10 species are too imperfect to enable us to refer them to any peculiar class.

II. *Older Pliocene Formations.*

These formations are not covered by the preceding, but are considered as of a more ancient era, because they contain a much greater number of extinct fossil shells. Like the preceding formations they exist in greatest perfection in Italy.

The Appenines constitute a range of mountains which branches off from the Ligurian Alps and passes down the Italian peninsula. At the foot of these mountains, both on the side of the Adriatic and the Mediterranean, is found a series of tertiary strata, which form a line of low hills occupying the space between the older chain and the sea. Brocchi first observed, that more than one-half of the shells in these tertiary strata agree with species now living in the Mediterranean, or in other seas chiefly of warmer climates.

The most important of these beds is a marl, which varies in colour from greyish brown to blue. It is very aluminous, and usually contains much calcareous matter and scales of mica. Sometimes it is thinly laminated, but often exhibits no lines of distinction throughout a considerable thickness. In some of the hills near Parma, this marl acquires a thickness of nearly 2000 feet, and is charged throughout with shells, many of which are such as inhabit a deep sea. They

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* For an account of the Geology of Rome, we refer to an excellent paper by Hoffmann, accompanied by a geological map inserted in Poggendorff's Annalen, xvi. 1.

often occur in layers so as to indicate a gradual accumulation. They are not flattened, but are filled with marl. Beds of lignite are sometimes interstratified, as at Medesano, four leagues from Parma. Subordinate beds of gypsum also occur in many places, as at Vigolano and Bargonæ, in the territory of Parma, where they are interstratified with shelly marl and sand.

The other member of the Subappenine group, the yellow sand and conglomerate, constitutes usually a border formation near the junction of the tertiary and secondary rocks. In some cases, as near the town of Sienna, we see sand and calcareous gravel resting immediately on the Appenine limestone, without the intervention of any blue marl. Alternations are there seen of beds containing river shells, with others filled exclusively with marine species, and oysters are attached to many of the limestone pebbles.

These tertiary strata have resulted from the waste of the rocks which now form the Appenines, and which had become dry land before the older pliocene beds were deposited; even at present, the rivers carry into the sea a sediment exactly similar to the marl above described. And yellow sand is thrown down by the Tiber near Rome, and by the Arno at Florence. The northern part of the Appenines, consists of a grey micaceous sandstone with an argillaceous base, alternating with shale, from the degradation of which brown clay and sand would result.

The shells contained in these tertiary-beds are soft when first taken from the marl, but they become hard when dried. The superficial enamel is often well preserved, and many shells retain their pearly lustre, and even part of their external colour, and the ligament which unites the valves. The microscopic shells abounding near Sienna are very perfect. In some large tracts of yellow sand it is impossible to detect a single fossil, while in other places they occur in profusion. These testacea are referrible to species and families of which the habits are extremely diversified, some living in deep, others in shallow water, some in rivers or at their mouths. Mr. Lyell saw a specimen of a *fresh water* univalve (*Limnea palustris*) taken from the blue marl near Parma full of small *marine* shells. Blocks of Appenine limestone are found in this formation drilled by lithodomous shells. The remains not only of testacea and corals but of fishes and crabs, are met with, as also those of cetacea, and even of terrestrial quadrupeds.

Mr. Lyell has pointed out the existence of these older pliocene formations along the coast of the Mediterranean, from Genoa (or at least the base of the Maritime Alps) to Nice. There is also a considerable thickness of the same tertiary strata on the borders of the Mediterranean at the eastern extremity of the Pyrenees, in the valleys of the rivers Tech, Tet, and Gly. They are very similar to the Italian beds, consisting partly of a great thickness of conglomerate, and partly of clay and sand, with subordinate beds of lignite. They abut against the primary.

Marine strata of the older pliocene period occur in patches at Malaga and Granada, in Spain. They have also been observed in the Morea by MM. Boblaye and Verlet.

The reader will find a list of the principal shells hitherto found in the older pliocene formations, at the end of the third volume of Lyell's Geology.*

A portion of the older pliocene formation occurs on the coast of Norfolk and Suffolk, where it is locally known by the name of *crag*, which is said to be a term applied in Suffolk to *sand*.

The extent of the *crag* has not yet been accurately defined. It rests sometimes upon the London clay, and sometimes upon chalk. It is first seen at Walton Nase, in Essex, where it is exposed on the cliff for 300 paces in length. It caps the cliffs on both sides of Harwich. Quarries of it are worked on the southern bank of the river Orwell, in Suffolk; and near Southwold, which is about two miles south of Lowestoff, it appears in the cliff together with sand and red loam covering the London clay. The same bed of shells is found upon digging through Suffolk and a great part of Norfolk. Mr. Woodward informs us that it is found at Cromer, and westward of that town at Coltishall, and round Norwich. Mr. Richard Taylor of Norwich has given us a section of its strata as they appear at Bramerton, on the southern bank of the Yare resting on the upper chalk.† The strata visible are twelve in number, and are as follows, beginning with the uppermost:—

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* The preceding account of the pliocene formations in Italy is taken from the third volume of Mr. Lyell's Geology.

† Geological Transactions (second series), i. 371.

	Thickness. Feet.	
1.	5	Sand without organic remains.
2.	1	Gravel.
3.	4	Loamy earth.
4.	1½	Ferruginous sand, containing hollow nodules.
5.	1½	Coarse white sand with a vast number of shells.
6.	1½	Gravel with fragments of shells.
7.	15	Brown sand with a seam of fragments of shells.
8.	3½	Coarse white sand with shells. Tellinæ and murices most abundant.
9.	15	Red sand with organic remains.
10.	1	Loamy earth with large stones and crag shells.
11.	1	Large flints in situ in the chalk.
12.	15	Chalk.

The thickness, exclusive of the chalk and flints, amounts to 49 feet.

Mr. Taylor has given us the following table of the shells found by him in this section:—

Shells.	Number of the bed in which the shell is found.
Emarginula reticulata	8
Turbo littoreus, 4 varieties	8
Scalaria similis	5, 8
Trochus similis?	8
——— concavus?	8
Turritella conoidea	8
——— trilineata (Smith)	8
Murex striatus	5, 8
——— carinatus	5, 8
——— latus	8
Cerythium?	8
Mya lata	5, 8, 10
Tellina ovata	5, 8, 10
——— obtusa	5, 8, 10
——— obliqua	5, 8, 10
——— bimaculata (Smith)	8
Mactra arcuata	8
——— cuneata	8
——— dubia	8
——— ovalis	8
Cardium Parkinsoni	5, 8, 10
——— angustatum	5, 8, 10
——— Edulina	5, 8, 10

Shells.	Number of the bed in which the shell is found.
Mytilus edulis	8, 10
——— antiquorum	8, 10
Modiola pallida	8
Pecten?	8, 10
Cyclas cuneiformis	8
Astarte plana, 3 varieties	8
Venus lentiformis	8
——— equalis	8, 10
Nucula Cobboldiæ	8
Balanus tesselatus	5, 8
——— crassus	5, 8
Fragments of lobsters and crabs	8
Palates and vertebræ of fishes	5, 8
Fragments of bone	5
Horns, vertebræ, and teeth, of large herbivorous animals	8
Fragments of wood	5, 8
Fragments of coal	5, 8

Mr. Lyell has given an interesting account of the constitution and position of these crag-beds along the coast of Norfolk and Suffolk. It lies over the chalk in an unconformable position; it consists often of beds alternately inclined and horizontal, and consisting of sand and comminuted shells. It would appear from Mr. Lyell's description, that these beds of sand must have experienced considerable derangement since they were originally deposited, for they occur bent, folded, and in every conceivable position with respect to each other.*

Mr. Lyell is of opinion that the extinct volcanic rocks at Olot, in Catalonia, belong to the older pliocene period. This volcanic tract extends about fifteen miles from north to south, and about six miles from east to west. The volcanic matter made its way through secondary rocks of sandstone and nummilitic limestone, supposed to be contemporary with the English green sand and chalk. There are about fourteen cones or craters, and the volcanic matter is basalt, scoriæ, &c. The reason for supposing these volcanoes to be of the age of the older pliocene rocks is that they in some places cover old alluvium.†

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* Lyell's Geology, iii. 171.

† Ibid. p. 183.

The date of the extinct volcanoes of the lower Rhine and the Eissel is equally uncertain with that of the Catalonian lava. Mr. Lyell has stated his reasons for referring these volcanic eruptions also to the older pliocene period.[*]

CHAP. VI.

MIOCENE FORMATIONS.

THE term *miocene*[†] has been applied by Mr. Lyell to those tertiary formations which contain shells, about one-sixth of which only belong to living species, while the remaining five-sixths constitute extinct species. A table containing 1021 of such shells is inserted at the end of Lyell's Geology, of which only 176 (or $\frac{1}{5\cdot8}$) are recent, while all the rest belong to extinct species. Mr. Lyell has given figures of the most characteristic shells found in this formation. They are

Voluta rarispina,
Mitra Dufrenii,
Pleurotoma denticula,
Nerita Plutonis.
Turritella Proto,
Fascioloria turbinelloides,
Pleurotoma tuberculosa.

The miocene beds lie under the older pliocene when both happen to occur together. The area covered by them in different parts of Europe is very considerable. For they occur in Touraine, in the basin of the Loire, and still more extensively in the south of France, between the Pyrenees and the Gironde. They have also been observed in Piedmont, near Turin, and in the neighbouring valley of the Bormida, where the Appenines branch off from the Alps. They are largely developed in the neighbourhood of Vienna, and in Styria. They abound in parts of Hungary, and they overspread extensive tracts in Volhynia and Podolia.

The miocene strata, called the *Faluns* of the Loire, have been observed to repose on a great variety of older rocks between Sologne and the sea, in which line they are seen successively to rest on gneiss, clayslate, coal measures, oolitic limestone, greenstone, chalk, and upper fresh-water formations of the Seine. They consist chiefly of quartzose gravel, sand, and broken shells. The beds are generally incoherent,

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[*] Lyell's Geology, iii. 193.

[†] *μειων*, *less*, and *καινος*, *new*.

but sometimes agglutinated together by a calcareous or earthy cement, so as to serve as a building stone. The thickness does not exceed 70 feet. They often bear a striking resemblance to the crag in appearance, the shells being stained of the same ferruginous colour, and being in the same state of decay, serving in Touraine, just as in Norfolk, to fertilize the arable land. Like the crag also they contain mammiferous remains, which are not only intermixed with marine shells, but sometimes encrusted with serpulæ, flustra, and balani. These terrestrial quadrupeds belong to the genera mastodon, rhinoceros, hippopotamus, &c. The assemblage considered as a whole being very distinct from those of the Paris gypsum. In these *faluns* M. Desnoyers has discovered the bones of the following quadrupeds:—

Palæotherium magnum,
Mastodon angustidens,
Hippopotamus major, minutus,
Rhinoceros leptorhinus, minutus,
Tapir gigas,
Anthracotherium (small species),
Sus,
Equus (small species),
Cervus,
An undetermined species of rodentia.

This formation resembles the *crag*, but is distinguished by the smaller number of recent shells which it contains.

The hills of Mont Ferrat and Superga, near Turin, belong also to the Miocene formations. The strata of these hills are inclined at an angle of more than 70 degrees. They consist partly of fine sand and marl, and partly of a conglomerate composed of primary boulders, which forms a lower part of the series. The high road which leads from Savona to Alessandria intersects these beds in its northern descent, and the formation may be studied along this line at Carcare, Cairo, and Spinto, at all which localities fossil shells occur in a bright green sand. At Piana, a conglomerate interstratified with this green sand, contains rounded blocks of serpentine and chlorite slate, larger than those near the summit of the Superga, some of the blocks being not less than nine feet in diameter.

When we descend to Acqui, we find the green sand giving place to bluish marls, which also skirt the plains of the Tanaro at lower levels. These newer marls are associated with sand

and are nearly horizontal, and appear to belong to the Older Pliocene Subappenine strata.

In Savoy, at the northern base of the great chain, there occurs a soft green sandstone associated with marls and conglomerate. It is called *molasse*, doubtless from its softness. It is of vast thickness, but shells have been so rarely found in it that they do not supply sufficient data for correctly determining its age. Mr. Lyell, from analogy with the Bormida beds, seems disposed to consider the molasse as a miocene formation.

A long succession of marine strata intervenes between the Alps and the plains of Hungary, which are divisible into three natural groups, each of vast thickness, and affording a great variety of rocks. They lie in strata nearly horizontal, but have a slight easterly dip, so that in traversing from west to east we commence with the oldest and end with the youngest beds. At their western extremity they fill an irregular trough-shaped depression, through which the waters of the Mur, the Raab and the Draven make their way to the lower Danube. They here consist of conglomerate, sandstone and marls, some of the marls containing marine shells. Beds also of lignite occur, showing that wood was drifted down in large quantities to the sea. In parts of the series there are masses of rounded siliceous pebbles, resembling the shingle banks which are forming on some of our coasts.

The second principal group is characterized by coralline and concretionary limestone of a yellowish-white colour. It is finely exposed in the escarpments of Wilden and in the hills of Ehrenhausen, on the right bank of the Mur. This coralline limestone is at least four hundred feet thick at Wilden, and therefore exceeds some of the most considerable of our secondary groups in England, as, for example, the *coral rag*. Beds of sandstone, sand and shale are associated with this limestone.

The third group, which occurs at a still greater distance from the mountains, is composed of sandstone and marl, and of beds of limestone, exhibiting here and there a perfectly oolitic structure. In this system fossil shells are numerous.

The middle group of these formations belongs indisputably to the miocene period; for the species of shells are the same as those of the Loire, Gironde, and other contemporary basins before noticed. The inferior or first group from the shells enumerated by Sedgewick and Murchison probably belongs to the same period. They specify

Mytilus Brardii,
Cerithium pictum,
——— pupæforme,
——— plicatum.

All of which characterize the miocene period.

The third or newest system which overlies the coralline limestone contains fossils which do not differ so widely from the miocene type as to authorize us to separate them.*

Mr. Lyell points out other miocene formations in Auvergne, Velay, Orleanais, the Upper Val d'Arno, Cadibona, Hungary, Transylvania, and Styria. The bones of fossil quadrupeds found in the Upper Val d'Arno by Mr. Pentland, belong to the following species:—

1. *Feræ.*

Ursus cultridens,
Viverra Valdarnensis,
Canis lupus, and another of the size of the common fox,
Hyæna radiata, fossilis,
Felis, a new species of the size of the panther.

2. *Rodentia.*

Histris, nearly allied to dorsalis,
Castor.

3. *Pachydermata.*

Elephas Italicus,
Mastodon angustidens,
——— taperoides,
Tapir,
Equus,
Sus scrofa,
Rhinoceros leptorhinus,
Hippopotamus major,
fossilis.

4. *Ruminantia.*

Cervus megaceros?

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* See Sedgewick and Murchison's paper in the Geol. Trans. (second series), iii. 301; and Lyell's Geology, iii. 212.

Cervus Valdarnensis,
——— new species,
Bos, bubalo affinis,
—— urus,
—— taurus.[*]

These are quite different from the animals whose bones are found in the Paris basin.

CHAP. VII.

EOCENE FORMATIONS.

THIS name[†] has been given by Mr. Lyell to a set of formations deposited at an earlier period than the miocene. The name was imposed, because an extremely small proportion of living species are contained in these beds. They indicate what may be considered as the *dawn* or commencement of the existing state of the animate creation upon the earth.

The total number of shells of this period is 1234, of which 42 only are living species, being nearly in the proportion of 3½ per cent. Of fossil species not known as recent 42 are common to the eocene and miocene epochs. In the Paris basin alone 1122 species have been found fossil, of which 38 only are still living. A list of most of these shells may be seen in M. Deshayes's table, at the end of the third volume of Lyell's Geology. Mr. Lyell has given figures of the following shells in plate third of the third volume of his geology, as characteristic of this formation:—

Voluta costaria,
——— digitalina,
Pleurotoma clavicularis,
Cassidaria carinata,
Nerita tricarinata,
Calyptræa trochiformis,
Turritella imbricataria,
Natica epiglottina,
Solarium canaliculatum,
Cardita planicosta.

The celebrated Paris basin was the first of the eocene for-

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[*] Lyell's Geology, iii. 220.

[†] From ἠως, *aurora*, and καινος, *new*.

mations which were accurately explored. For our knowledge of these deposits we are indebted to the labours of Cuvier and Brongniart. They were ascertained to fill a depression in the chalk, which constitutes the fundamental rock at Paris and the neighbouring country.

Mr. Lyell considers many of the Paris beds as identical with certain beds in Auvergne, which seem to have been gradually deposited in lakes at that time existing in that part of France.

Immediately over the chalk in the Paris basin lies a layer of broken chalk flints, often cemented into a breccia by siliceous sand.

Upon this flinty stratum, or if it be wanting, upon the chalk itself rests frequently a deposit of clay and lignite, called the *first fresh water formation* or *plastic clay formation*, by Brongniart and Cuvier. It is composed of fresh water shells and driftwood, and was at first regarded as a proof that the Paris basin had originally been filled with fresh water. But it has been since shown that this group is not only of very partial extent, but is by no means restricted to a fixed place in the series, for it alternates with the *calcaire grossier*, and is repeated in the very middle of that limestone at Veaugirard, Bagneux, and other places where the same Planorbes, Paludina, and Limnei occur, as has been shown by M. Constant Prévost. Its origin was doubtless a river entering a bay of the sea, charged with argillaceous sediment, and drifting down occasionally fresh water shells and wood.*

The next bed was called by Cuvier and Brogniart *calcaire grossier* or *first marine formation*. It is composed of a coarse limestone, often passing into sand. It contains by far the greater number of the fossil shells, which characterize the Paris basin. No fewer than 400 distinct species have been derived from a single locality near Grignon. They are imbedded in a calcareous sand chiefly formed of comminuted shells, in which nevertheless individuals in a perfect state of preservation, both marine, terrestrial, and fresh water species are mingled together, and were evidently transported from a distance. Some of the marine shells may have lived on the

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* Brongniart, in his *Tableau des terrains qui composent l'écorce du Globe*, published in 1829, (p. 184), defends his original opinion with much ingenuity, and advances arguments in support of it possessed of considerable weight. But the opinion of Prévost is so much simpler, and explains the seeming anomalies in so satisfactory a way that I am disposed to adopt it.

spot, but cyclostoma and limnea must have been brought there by rivers and currents, and the quantity of triturated shells implies considerable movement in the waters. Nothing is more remarkable in this assemblage of fossil shells than the great proportion of species referrible to the genus Cerithium. There occur no fewer than 137 species in the Paris basin, and almost all of them in the *calcaire grossier*. Now the living testacea of this genus inhabit the sea near the mouths of rivers, where the waters are brackish. Hence their occurrence in the marine strata of the Paris basin accords with the statement of M. Prévost, that a river flowed into the gulf and gave rise to the beds of clay and lignite in the plastic clay bed above mentioned.

The next bed in order is a compact siliceous limestone, called by Brongniart and Cuvier *calcaire siliceux.* It resembles a precipitate from the waters of mineral springs. It is for the most part void of animal remains; but in some places it contains fresh water and land species, and never any marine fossils. The siliceous limestone and the calcaire grossier occupy distinct parts of the basin, the one attaining its fullest development in those places where the other is of slight thickness. They also alternate with each other towards the centre of the basin, as at Sergy and Osny, and there are even points where the two rocks are so blended together that portions of each may be seen in hand specimens.

From these facts and some others, it has been concluded, that while to the north, where the bay was probably open to the sea, a marine limestone was formed, another deposit of fresh water origin was introduced to the southward or at the head of the bay.

The next group in order is the *gypsum*, and the *white* and *green marls* of Cuvier and Brongniart. These were once considered to be entirely subsequent to the groups already described. But Prévost has shown that, in some localities, they alternate repeatedly with the calcaire siliceux, and in others with some of the upper members of the calcaire grossier. The gypsum, with its associated marls and limestone is in greatest force towards the centre of the basin where the two groups just mentioned are less fully developed. And M. Prévost infers, that while those two principal deposits were gradually in progress, the one towards the north and the other towards the south, a river descending from the east may have brought down the gypseous and marly sediment.

The next group, called the ***second*** or ***upper marine formation***, by Cuvier and Brongniart, consists in its lower division of green marls, which alternate with the fresh water beds of gypsum and marl above described. Above this division the products of the sea exclusively predominate, the beds being chiefly formed of micaceous sand, 80 feet or more in thickness, surmounted by beds of sandstone with scarcely any limestone. The summits of a great many platforms and hills in the Paris basin consist of this upper marine series, but the group is much more limited in extent than the calcaire grossier.

The uppermost of the formations in the Paris beds is called by Cuvier and Brogniart the ***third fresh water formation.*** It consists of marls interstratified with beds of flint and layers of flinty nodules. One set of siliceous layers is destitute of organic remains, the other replete with them. Gyrogonites, or fossil-seed vessels of charæ, are found abundantly in these strata, and all the animal and vegetable remains agree well with the hypothesis, that after the gulf or estuary had been silted up with the sand of the upper marine formation, a great number of marshes and shallow lakes existed, like those which frequently overspread the newest parts of a delta.

The entire series of these Paris beds must have required a long lapse of ages for its accumulation, yet they all belong to the eocene period. The shells of the different fresh water groups, constituting at once some of the lowest and uppermost members of the series, are nearly all referrible to the same species, and the discordance between the marine testacea of the calcaire grossier and the upper marine sands is very inconsiderable. M. Deshayes has made a curious observation respecting the changes which one species, the ***cardium porulosum***, has undergone during the long period of its existence in the Paris basin. Different varieties of this cardium are characteristic of different strata. In the oldest sand of the Soissonais (a marine formation underlying the regular beds of the calcaire grossier) this shell acquires but a small volume, and has many peculiarities which disappear in the calcaire grossier. In these the shell attains its full size and many peculiarities of form, which are again modified in the uppermost beds of the calcaire grossier, and these last characters are preserved throughout the whole of the upper marine series.

In some parts of the calcaire grossier microscopic shells are very abundant. They belong to the order of *Cephalopoda*, the animals of which are the most free in their motions, and most advanced in their organization of all the mollusca. They are often in an excellent state of preservation, and their forms are singularly different from those of the larger testacea.

The gypsum at the base of Montmartre, is seen distinctly to alternate with soft marly beds of the calcaire grossier, in which cerithia and other marine shells occur. But the great mass of gypsum may be considered as a purely fresh water deposit, containing land and river shells, together with fragments of palm wood, and great numbers of skeletons of quadrupeds and birds, an assemblage of organic remains which have given great celebrity to the Paris basin. In this gypsum formation, Cuvier discovered the bones of two new genera of animals, which he distinguished by the names of *Palæotherium* and *Anoplotherium*. The palæotherium resembles the tapir. Ten species have been described by Cuvier, varying in size from that of the rhinoceros to that of the hog and sheep. They appear all of them to have been herbivorous animals. The genus anoplotherium resembles the camel. The tail is as long, if not longer, than the body, at the same time very thick and strong. Five species are described by Cuvier, all of which occur in this gypsum formation.

The remains of three carnivorous animals have been found in the same beds. One of these resembles the fox; the second is either an unknown species of *canis*, or of a genus intermediate between the *canis* and *viverra*: the third is allied to the ichneumon, but is double its size.

The *Lophiodon* is another new genus, nearly allied to the tapir. Twelve species have been determined by Cuvier, and one of them is of gigantic dimensions.

The bones of a species of tapir of gigantic size were also found in the same formation. It is 18 feet long and 12 feet high, thus equalling the skeleton of the mastodon or the elephant.

Cuvier has ascertained and classified the fossil remains of 78 different species of extinct quadrupeds, found either in this formation or in those above it in the series. Forty-nine of these are species hitherto entirely unknown to naturalists. Eleven or 12 others have such entire resemblance to species already known, as to leave no doubt of their identity. The remaining 16 or 18 have considerable traits of resemblance to known species; but the comparison has not been made with so much precision as to remove all doubt.

Of the 49 new species, 27 are referrible to 7 new genera, while 22 are referrible to genera or subgenera already known. The whole genera and subgenera to which the fossil remains of quadrupeds hitherto investigated are referrible, are 36, including those belonging both to known and unknown species.

Of the 78 species, 15 which belong to 11 genera, are animals of the class of oviparous quadrupeds; while the remaining 63 are of the mammiferous class. Of these last, 32 species are hoofed animals, not ruminating, and reducible to 10 genera; 12 are ruminating animals belonging to 2 genera; 7 are gnawers referrible to 6 genera; 8 are carnivorous quadrupeds belonging to 5 genera; 2 are toothless animals of the sloth genus; and two are amphibious animals of two distinct genera.

For a particular account of all these fossil animals (many of which have been found in alluvial beds) we must refer the reader to Cuvier's great work on *the Fossil Remains of Quadrupeds*. But it may be interesting to specify a few of the most remarkable.

1. *Megatherium*. This animal belongs to the order of *bradypus*, or *sloth*. A complete skeleton was found in the alluvial soil near Buenos Ayres, and sent to Madrid. Afterwards another was discovered near Lima, and a third in Paraguay. The Madrid skeleton is 14 feet long and 7 feet high. It is so rude and unshapely, that the clumsy skeleton of the elephant and rhinoceros, and even the massive and rugged bones of the hippopotamus, appear, when placed beside it, slender and light. It is one of the largest and most massive of all the fossil quadrupeds hitherto discovered. Judging from its structure, its motions seem to have been slow and dragging; and, with the exception of its claws, it appears to have been more defenceless than any other of the large quadrupeds. The form of the teeth shows that it lived on vegetables. Its long claws are supposed to have been used for digging up the roots on which it is conjectured to have fed.

2. *Elephant*. The fossil elephant, or mammoth, as it is called by the Russians, is different from both the species of that animal at present existing. The alveoli of the tusks are much larger, and the zigomatic arch of a different form. The

vacuity between the branches of the jaws at the fore part is wider, and the lower jaw, instead of terminating in a kind of pointed apophysis, is rounded off. The tusks are more incurvated.

The remains of this animal have been found both in North America and in Asiatic Russia. Indeed an entire animal was discovered in the latter country in a state of complete preservation, having been frozen in the snow. It will be worth while to transcribe Cuvier's account of this curious discovery.

"In the year 1799, a Tungusian fisherman observed a strange shapeless mass projecting from an ice bank near the mouth of a river in the north of Siberia, the nature of which he did not understand, and which was so high on the bank as to be beyond his reach. Next summer he observed the same object, which was then rather more disengaged from the ice, but he was still unable to conceive what it was. Towards the end of the following summer, in 1801, he could distinctly see that it was the frozen carcase of an enormous animal, the entire flank of which, and one of its tusks, had become disengaged from the ice. In consequence of the ice beginning to melt earlier and to a greater degree than usual, in 1803, the fifth year after the discovery, the enormous carcase became entirely disengaged, and fell down from the ice crag on a sand bank forming part of the coast of the Arctic Ocean. In the month of March of that year, the Tungusian carried away the two tusks, which he sold for 50 rubles, and at this time a drawing was made of the animal, of which Cuvier got a copy.

"Two years afterwards, or in 1806, Mr. Adams went to examine the animal, which still remained on the sand bank on which it had fallen from the ice, but its body was then greatly mutilated. The Jakuts of the neighbourhood had taken away considerable quantities of its flesh to feed their dogs, and the wild animals, particularly the white bears, had also feasted on the carcase. Yet the skeleton remained quite entire, except that one of the fore legs was gone. The entire spine, the pelvis, one shoulder blade, and three legs, were still held together by their ligaments and by some remains of the skin, and the other shoulder blade was found at a short distance. The head remained covered by the dried skin, and the pupil of the eyes was still distinguishable. The brain also remained within the skull, but a good deal shrunk and dried; and one of the ears was in excellent preservation, still retaining a tuft of strong bristly hair. The upper lip was a good deal eaten away, and the under lip was entirely gone, so that the teeth were distinctly seen. The animal was a male, and had a long mane on its neck.

" The skin was extremely thick and heavy, and as much of it remained as required the exertion of ten men to carry away, which they did with considerable difficulty. More than 30 lbs. weight of the hair and bristles of this animal were gathered from the wet sand bank, having been trampled into the mud by the white bears while devouring the carcase. Some of this hair was presented to the Natural History Museum of Paris, by M. Targe, censor in the Lyceum of Charlemagne. It consists of three different kinds; one of these is stiff black bristles, a foot or more in length; another is thinner bristles, or coarse flexible hair of a reddish brown colour; and the third is a coarse reddish brown wool which grew among the roots of the long hair. These afford an undeniable proof that this animal had belonged to a race of elephants inhabiting a cold region and now no longer existing, and by no means fitted to dwell in the torrid zone. It is equally evident, that this enormous animal must have been frozen up by the ice at the moment of its death."

Remote, then, as the period must be when this animal existed on the earth, still it must have been when the temperature of the globe was nearly the same all over the surface as at present.

3. *Cervus giganteus*, or *Irish Elk*. This gigantic and magnificent species is found in a fossil state in Ireland, Isle of Man, England, France and Germany. There is a complete skeleton from the Isle of Man in the College museum of Edinburgh. It is six feet high, nine feet long, and from the ground to the tip of the right horn nine feet seven inches. It was imbedded in a loose shell marl, in which were numerous branches and roots of trees.

4. *Ornithocephalus*. This is a most extraordinary animal, found imbedded in limestone at Eichstadt. There are two species described by Sommering, the *longirostris* and *brevirostris*. Naturalists are not agreed in opinion to what tribe of animals it ought to be referred. Cuvier considered it as amphibious, Blumenbach as a bird, Collini as a fish, while Sommering conceives that it belongs to the mammalia, and places it near the bats.

5. *Man*. During the agitation of the diluvial controversy,

many descriptions appeared of the fossil remains of man, said to have been found in various places; but a closer examination showed that all these supposed fossil human bones belonged in reality to inferior animals. Thus the famous *homo diluvii testis* of Scheuchzer was found to be a gigantic fossil lizard. The fossil bones of Cerigo, so confidently described by Spallanzani as human, are now admitted to belong to quadrupeds. Human remains, however, have been found in the fissures of rocks, and in alluvial strata. About the beginning of the present century, human bones were found in a compact calcareous rock in the island of Guadaloupe. The rock is composed of the debris of corralines and shells, and is obviously of very recent formation. The annual formation of a similar rock may be witnessed at present on the Cornish coast.* A mass of this Guadaloupe rock, containing a well preserved human skeleton, but wanting the head, was sent home by the French commander of that island, during the French revolutionary war, to Paris. The ship containing it having been captured by Sir Alexander Cochrane, he sent the fossil skeleton to Lord Melville, who was at that time first Lord of the Admiralty. His Lordship presented it to the British Museum, where it may still be seen.†

Human bones have been occasionally met with in caverns, but these remains, in all cases hitherto observed, are comparatively recent.

(1.) They have been found encrusted with stalactite in a mountain limestone cavern at Barrington, in the Mendip hills. This cave was either used as a place of sepulchre in early times, or resorted to as a place of refuge by wretches who perished in it during some of the numerous cases of devastating warfare that occurred in ancient times. The bones are chiefly deposited on one side of the cavern, as in a sepulchre catacomb.

(2.) Two analogous caves occur in mountain limestone in South Wales; one at the Mumbles, near Swansea. From the position of the bones they seem to be the remains of a number of bodies thrown in after a battle. The other cavern is also in mountain limestone at Llandebie, in Caer-

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* Dr. Paris has given an interesting account of this formation in the first volume of the Transactions of the Geological Society of Cornwall.

† An excellent account, with an engraving, of this fossil skeleton, together with an account of the rock in which it occurs, drawn up by Mr. König, may be seen in the Phil. Trans. for 1814, p. 107.

narvonshire. About twelve skeletons were found in it, arranged in parallel rows. This cave had obviously been used as a place of burial.

(3.) The cavern discovered at Bize, in the Department of l'Aude, at the foot of the Pyrenees, in 1829, contains also human bones attached to the rock, and mixed with the bones of other animals, and of land shells. Some of these bones belong to two different species of the stag at present extinct; but other bones are mixed with them of animals still existing, and also both sea and land shells belonging to species to be found still in the neighbouring country, and in the Mediterranean sea. With these are mixed fragments of pottery, very similar to those kinds known under the name of Etruscan pottery. From these facts it is obvious that the bones found in this cavern are of two different eras: 1. Those of the extinct animals are doubtless of the same era as the similar bones found in the Kirkdale and other caverns. 2. The human bones, and those of other animals still existing, are probably of a very remote date, but they must belong to a period when the face of the earth was similar to what it is at present.

Human bones have been found also in the caverns of Pondre and Souvignargues, in the department of Gard, near the mouth of the Rhone. These caverns exist in limestone of the newest formation. They are filled with the soft mud to which Buckland has given the name of *diluvium*. It contains the bones of hyænas, rhinoceroses, stags, &c. precisely in the same state as in the cave of Kirkdale. The human bones are mingled with these sparingly, and are described as absolutely in the same state. Along with them occur also fragments of the rudest kind of pottery. The human bones, those of the extinct animals, and the pottery, as far as can be determined from their position and state, seem all of an age. If any instance occur of antediluvian human bones, this is one; but the best description of these caverns which I have seen is imperfect. A more minute and careful investigation would be requisite before we can consider a fact of so much importance as established.*

The celebrated basins of London and Hampshire, first accurately described by Mr. Webster, belong also to the eocene period. The London basin is bounded by rising grounds

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* See the Annales des Mines (second series), v. 517.

composed of chalk, except where the sea intervenes, and there is every reason for believing that the chalk passes beneath all the tertiary strata of which this basin is composed. The strata belonging to the London basin have been divided into three series or groups:—

1. The plastic clay and sand, which is lowest,
2. The London clay,
3. The Bagshot sand, which is uppermost.

The plastic clay, in some places, attains a thickness of 400 or 500 feet. It consists principally of an indefinite number of beds of sand, shingle, clay and loam, irregularly alternating. Some of the clay is used in potteries: hence the term *plastic clay* has been applied to the whole formation. The beds of shingle are composed of perfectly rolled chalk flints, with here and there small pebbles of quartz. Heaps of these materials seem to have remained long covered by a tranquil sea. Dr. Buckland, in a part of this formation at Bromley, observed a large pebble, to which five full grown oyster shells were affixed in such a manner as to show that they had commenced their first growth upon it, and remained attached through life.*

In some of the associated clays and sand perfect marine shells are met with, which are of the same species as those of the London clay. Indeed, the line of separation between the London and plastic clay is quite arbitrary. In the midst of the sands of the lower series a mass of clay occurs 200 feet thick, containing septaria, and replete with the usual fossils of the neighbourhood of London.

The arenaceous beds are chiefly laid open on the confines of the basins of London and Hampshire, in following which we discover in many places great beds of perfectly rounded flints. This is the case with the hills of Comb Hurst and Addington, which form a ridge stretching from Blackheath to Croydon. Here they have much the appearance of banks of sand and shingle formed near the shores of the tertiary sea.

Organic remains are extremely rare in the plastic clay, but when any shells occur they are of the eocene species. Vegetable impressions and fossil wood sometimes occur, and even beds of lignite. But the *species* of none of these plants has been ascertained.

This formation occupies a greater extent of surface in the

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* Geol. Trans. iv. 300.

south portion of Hampshire than in Essex, Surrey and Kent. For the fullest account of its extent in these places we refer to Conybeare and Phillips' *Outlines of the Geology of England and Wales*, and to Mr. Greenough's *Geological Map*.

The London clay consists of a bluish or blackish clay, occasionally passing into a calcareous marl, rarely into a solid rock. Its thickness sometimes exceeds 500 feet. It contains many layers of ovate or flattish masses of argillaceous limestone, which in their interior are generally traversed in various directions by cracks, partially or wholly filled by calcareous spar. These masses, called *septaria*, are sometimes continued through a thickness of 200 feet.

A great number of the marine shells of this clay have been identified with those of the Paris basin. A list of these has been given by Mr. Lyell, in the Appendix to the third volume of his *Geology*. The list was drawn up by M. Deshayes from specimens in his own collection.

No remains of terrestrial mammalia have as yet been found in this clay, but the occurrence of bones and skeletons of crocodiles and turtles prove the existence of neighbouring dry land when the clay was deposited. About 800 different kinds of ligneous seed vessels of plants, some of them resembling the cocoa nut and other species of tropical regions, have been found in the Isle of Sheppey in this formation.*

In the London clay 15 species of fossil plants have been discovered, none of which are recent plants. Of these, twelve are plants belonging to the cryptogamia class ; two are palms; and one is a caulinites, described by M. A. Brongniart.

The third and uppermost group, usually termed *Bagshot sand*, rests conformably on the London clay, and consists of siliceous sand and sandstone, devoid of organic remains, with some thin deposits of marl associated. From these marls a few marine shells have been obtained, which are in an imperfect state, but appear to belong to the eocene species common to the Paris basin. Mr. Warburton collected several, of which the following are the chief:—The Reading oyster, a Pecten, a large and small cardium, a pectunculus, nucula margaritacea, two species of Citheræa, a shell resembling solen radiatus, a tellina, a dentatium, strombus pes-pelecani, calyptræa trochiformis in great perfection, and several imperfect turbinated

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* See an account of these, with figures, by Dr. Parsons, Phil. Trans., 1757, p. 396.

shells. He found also a shark's tooth, pyritous wood, and what appeared to be the seed vessel of a plant.*

For an account of the eocene formations in the Isle of Wight and the opposite coast of Hampshire, we refer the reader to Mr. Webster's papers in the *Geological Transactions*, to Englefield's *Isle of Wight*, to Sedgewick's paper in the *Annals of Philosophy* for 1822, and to Lyell's papers in the *Geological Transactions*, vol. 2d, second series.

Remains of tortoises and the teeth of crocodiles have been found in the Isle of Wight basin, and more recently bones of mammalia corresponding with those in the Paris gypsum beds. In marl, alternating with a limestone quarried for building near Ryde, the tooth of an Anoplotherium, and two teeth of the genus Palæotherium, were found. The tooth of the Anoplotherium was first observed by Mr. Allan, and his discovery was confirmed and extended by Mr. Pratt.†

The British eocene strata are nearly conformable to the chalk on which they rest, being horizontal where the strata of chalk are horizontal, and vertical where they are vertical. The surface of the chalk had been furrowed by the action of the waves and currents, before the plastic clay and its sands were superimposed. Thus at Rochester and Gravesend, in the quarries, fine examples are seen of deep indentations on the surface of the chalk, into which sand, together with rolled and angular pieces ofchalk flint, have been swept.‡

Mr. Lyell considers the beds in the lacustrine basins of Auvergne, Cartal, and Velay, to belong also to the eocene period. Many of the extinct volcanoes of that country may be of the same age. A portion of eocene formation occurs also in the Cotentin, and small portions of it are scattered over the primary deposits in Bretagne.

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* See Warburton on the Bagshot sand, Geol. Trans. (2d series), i. 48.

† Proceedings of the Geological Society, No. 18, p. 239.

‡ See Lyell's Geology, iii. 282, and Conybeare and Phillips' Outlines of the Geology of England and Wales, p. 62.

CHAP. VIII.

CHALK FORMATION.

The chalk, which constitutes so important a feature in the south of England and the north of France, constitutes the uppermost of what geologists denominate the *secondary formations*.

The nature and qualities of chalk are so generally known, that it is unnecessary to describe it minutely. The best chalk used for economical purposes is of a pure white, has an earthy fracture, a meagre feel, adheres to the tongue, and stains the fingers. It is dull, opaque, soft, has a specific gravity of 2·3, and is never crystallized. When pure it contains nothing but carbonate of lime. Magnesia has been detected in some specimens of French chalk. Clay and sand are rather common mixtures in it. Some of the lower beds have a red colour, probably derived from iron.

In the south of England chalk is occasionally used as a building stone. The abbey of Hurley in Berkshire, and its parish church, anciently a chapel, are said to be built of it. The mullions and arches of St. Catherine's chapel, near Guildford, are of chalk that contains flints. The abbey of St. Omar, ruined during the French revolution, was entirely constructed of flints, and retains all its beautiful gothic ornaments in great perfection.

The chalk formation is usually divided into three beds, namely, the *upper chalk*, the *lower chalk*, and the *chalk marl*, which is lowest of all.

The upper chalk appears in most places in England, wherever occasional openings have been made in the very large tract of country occupied by it. The inferior beds may be traced along the lower regions of the escarpment presented by the hills of this formation.

The upper chalk is soft, but the lower is much harder, does not mark, and is usually distinguished by the name of *hard chalk*. One of the most remarkable circumstances connected with chalk, is the occurrence of those numerous nodules of flint which alternate through the greater part of its mass. They are constantly present in the upper chalk, but rare in the under chalk, at least in England, for the rule is said not to hold in France. The chalk which occurs in the county of Antrim, in Ireland, is as hard as common mountain limestone, yet it contains abundance of flints. Hence it was probably at first in the state of soft chalk, but indurated by the action of the numerous trap beds which seem to have been forced up in that country in a state of fusion.

These flint nodules assume the most extraordinary forms. The siliceous matter seems to have been in a state of solution, probably in water, and to have been gradually deposited in alcyonia, sponges, &c., at that time existing in the chalk-beds.

Veins of flint traversing the regular strata at various angles may be observed generally when any extensive range of chalk cliffs are exposed. For example, in the Isle of Thanet, near Brighton, and in the Isle of Wight. The flint filling such veins is usually tabular.

The flints which have been washed out from the chalk at a remote period occur in the various deposits of gravel. From their superficial position, and the loose texture of the mass in which they occur, exposed for ages to the influence of the atmosphere and the percolation of water, they have been much altered and have undergone changes somewhat analogous to those which may be produced in them by fire. The black colour is rendered less intense, or changed to brown, yellow, or red. These different colours are sometimes arranged in zones parallel to the outward surface of the pebble.

The flint nodules often contain cavities lined with tubercular chalcedony or quartz crystals. Whenever chalcedony occurs in flint, a careful examination will generally detect the presence of a sponge or alcyonium.

Besides flints, subordinate beds of fuller's earth are occasionally met with in chalk. The chalk very often contains masses of iron pyrites, varying in size from that of a pea to several inches in diameter. They are usually crystallized, and exhibit when broken a diverging fibrous structure. They frequently occur cylindrical, and were formerly picked up and preserved under the name of *thunderbolts.*

At Bishopton down, near Warminster, in Wiltshire, enormous blocks of crystallized carbonate of lime occur in chalk. One of these, weighing 50 cwt., and measuring between 30 and 40 cubic feet, was cut into slabs for chimney pieces at Mr. Noel's, a stone mason at Warminster.

A brown or blackish brown substance has been observed coating the chalk in several places in Suffolk. It has sometimes the appearance of a sooty powder, but is occasionally fibrous. It is conjectured to be oxide of manganese.

The chalk formation stretches with little interruption from Flamborough Head, a remarkable promontory on the coast of Yorkshire, to near Sidmouth, on the coast of Devonshire, forming a range of hills often of considerable elevation, and of which the most precipitous escarpment is generally on the north-western side. Another range of hills branches from it in the south of England.

From Flamborough Head the chalk proceeds south as far as Bridlington quay, but from that to the mouth of the Humber the coast is alluvial. The chalk hills pass south, constituting the wolds of Yorkshire and Lincolnshire. They disappear in the Wash, which is entirely alluvial. Near the shore of the north western part of Norfolk, the chalk appears again, constituting a ridge of hills running south about 15 miles, and then disappears, sinking under the diluvial sand of Norfolk. It appears again on the north of Thetford, and passes on uninterruptedly by Newmarket in Suffolk, a little to the east of Cambridge, till it reaches Marlborough Downs in Wiltshire, where it is broken through by the village of Kennet.

In Wiltshire the chalk formation exhibits its greatest extent, being more than fifty miles long, from east to west, and about twenty miles broad from north to south.

From this great central mass a branch of chalk hills passes south-west through Dorset, and bending east, not far from Dorchester, constitutes the northern part of the isle of Purbeck, and passing across Alum Bay forms the central and most elevated portion of the Isle of Wight, extending quite across the island, and terminating at the east end in a precipitous cliff.

Another branch runs almost due east, by Winchester, Arundel and Lewis, till it terminates in the sea at Beachy-head.

A third branch runs a little north-east, by Farnham and Guildford, and terminates by its southern side in the Channel at Folkestone, west of Dover.

Each of these branches constitutes so many chains of low round-backed hills, in general remarkable for their beauty and fertility. The number of plants found growing on the chalk is in general greater than on any other soil, and the crops which it produces, are, in general, excellent.

The isle of Thanet, which is composed of chalk, though not far from the north-west chain, is, in fact, unconnected with it, being separated by a trough occupied by the plastic clay formation, which lies above the chalk.

The fossils in the chalk beds are numerous, but the variety of genera and species is not very great, and not one of them agrees in every respect with animals at present inhabiting the earth. Hence it was obviously formed at a period indefinitely earlier than the eocene beds.

The remains of several vertebral fish occur; teeth of a species of shark, nearest in appearance to those of the *squalus galeus;* two varieties of palate bones belonging to unknown genera, have been found, not to mention various vertebræ and scales of fish.

We find in the chalk the following univalve and bivalve shells:

Ammonites.
Scaphites.
Belemnites.
Trochus.
Cirrus.
Turbo.
Serpulæ.
Spirorbes.
Ostreæ.
Pecten.
Terebratulæ.
Majus.
Plagiostoma spinosa.
Dianchora lutea.
Inoceramus.
Balanus.*

The family of echinites may be considered as characterizing the chalk formation, and the species are at least equal in number to that of all the shells found in it. The following table exhibits a list of the zoophytes found in chalk.

Ananchites ovata.
——— pustulosa.
Nucleolithes rotula.
Galerites albogalerus.
——— vulgaris.
——— subrotundus.
——— conoideus.
Spatangus cor-anguinum.
——— Bufo.
——— rostratus.
Cidarites vulgaris.
——— saxatilis.
——— Königii.
——— corollaris.

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* See a table of the different species given by Brongniart in his *Tableau des Terrains qui composent l'écorce du Globe,* p. 403.

Cidarites papillata.
Asterias.
Pentagonaster semilunatus.
Pentaceros lentiginosus.
Apiocrinites ellipticus.
Pentacrinites.
Marsupites ornatus.
———— Milleri.
Caryophyllia cyathus.
———— costellata.
Turbinolia Königii.
Alcyonium pyriformis.
Spongia ramosa and many other species.
Choanites subrotundus.
———— flexuosus.
Königii.
Ventriculites radiatus.
———— alcyonoides.

The plants found in chalk are:

Confervites fasciculata.
———— egagropiloides.
Fucoides lyngbianus.*

The following subdivisions of the family of echinites fou in the chalk may be of use to beginners:—

1. Helmet shaped—*Echinocorys*, *Ananchytes*.
2. Conical—*Conulus*, *galerites*.
3. Heart-shaped—*Spatangus*.
4. Spheroidal, with the mouth and vent on opposite pol Lamark has divided them into two genera. 1. Tubercl perforated to admit the passage of muscular filaments, whi assist in the motion of the spines—*Cidaris*. 2. The tubercl imperforate; the spines, which are smaller, being moved the contractions of the outer skin only—*Echinus*.

The substance of sponges, found in such abundance fos in chalk, consists, as to their interior texture, of a mass of i terwoven fibres, penetrated by larger pores regularly or ir gularly disposed. These fibrous reticulations sometimes r confusedly together, so that the meshes present no regular determinate figure; sometimes they are regularly disposed as to give the whole mass a plicated character. Of the i

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* This table is taken from Brongniart's *Tableau des Terrains*, beca of its shortness. The reader will find a much more complete list in De Beche's Manual of Geology, p. 270.

gularly reticulated sponges at least four genera have been observed; namely:

1. Ramifying.
2. Palmated.
3. Turbinated or funnel-shaped.
4. Fig-shaped.

Only fourteen species of fossil plants have been hitherto observed in the chalk: of these thirteen species are cryptogamous plants, eleven being fucoides and two confervites. One species belongs to the order of Cycadeæ, and is therefore a dicotyledonous plant.

It has been already mentioned that the chalk formation is usually hilly; but the hills are not high. The highest chalk hill in England, Inkpen, in Wiltshire, is 1011 feet above the level of the sea. Wilton Beacon, the highest chalk hill in Yorkshire, is 809 feet high, and various hills in Hampshire, Kent and Surrey, are nearly as elevated. Near Dover the chalk with flints is about 480 feet thick, while the thickness of the chalk without flints is about 140 feet. At Handfast Point, on the coast of Dorset, the flinty chalk is 600 feet thick, and that without flints about 200 feet. At Culver Cliff in the Isle of Wight, the beds of chalk are vertical and extend about a quarter of a mile or 1300 feet. This may be considered as the greatest thickness of the chalk in England.

The chalk formation appears to extend over an area of great extent, occupying the interior of the great European basin, reaching probably from the banks of the Thames to those of the Dniester. But the beds cannot be traced continuously throughout the borders of this area, though this can be done with the western limits of it in England and France. In the central parts of Europe it is greatly concealed, partly by the overlying of the more recent tertiary deposits, and partly by the vast accumulation of diluvial debris which conceal from observation the rocks throughout so large a portion of the north of Germany.

The northern limit may be traced in the line of the Baltic in the island of Rugen, where chalky cliffs present themselves on its northern coast. They occur also on the neighbouring continent, in Pomerania and Mecklenburg. A small chalk cliff may be observed near Malmo, in Sweden, crossing to the opposite coast of Zealand, and including the small island of Mona on the south. From Mona the line of chalk has not been traced. It probably traverses Holstein to the mouth of the

Elbe, where it crosses the German Ocean to Flamborough Head.

In France the limits of the chalk correspond to the south coast of England. Its western edge is at the mouth of the Seine. It proceeds south to Blois on the Loire, where the formations above the chalk overlie and conceal its southern extremity. It appears again at Montargis, and turning northwards runs by Troyes, Rheims and Valenciennes. North of Valenciennes the edge of the chalk appears to trend east, but it is generally covered by the sandy superstrata of the Netherlands. It may, however, be seen on the south of Maestricht and at Henri Chapelle, near Aix.

From a memoir by M. Dufrenoy,* it appears that there is a large tract of country in the south-west of France and upon the declivity of the Pyrenees, on the French side, which corresponds in its fossils with the chalk and green sand of the north of France and England, and of course belongs to the same era.

This formation, besides the fossils which characterize the chalk beds, and which have been already enumerated, contains several others peculiar to itself, which have been enumerated by M. Dufrenoy. It contains also subordinate beds, which had never been suspected to exist in chalk; namely, beds of fossil wood, of gypsum, of sulphur, and probably also of rock salt.

The chalk, instead of possessing the softness, and dulness and opacity, which characterize it elsewhere, is frequently hard and crystalline. This is the reason why, before the investigations of Dufrenoy, the district had been referred to formations at least as old as the oolite and new red sandstone. M. Dufrenoy has elucidated his description by various sections, exhibiting in detail the structure of the country.

The chalk appears again in Westphalia, to the north of the coal fields of Rahn. After an interruption from the alluvia of the Lippe it appears again in Osnaburg, and forms at the foot of the *Muschelkalk* formation, a series of little escarpments.

To the north of the secondary hills of Westphalia, the whole district is well known to present the appearance of an uniform and vast sandy heath, covered with a deep accumulation of diluvial gravel, in the midst of which occur enormous rounded

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* Annales des Mines (second series), viii. 175, 321.

blocks of granite from Sweden. The great mass of this gravel consists of chalk flints, well marked, and bearing traces of all the characteristic fossils. At Luneburg the fortifications are partly constructed of a rock of gypsum, and about a quarter of a mile hence on the road to Hamburgh, Mr. Conybeare, to whom we owe all these details, discovered a chalk pit which had escaped the attention of former observers. It contained the usual alternation of flints, and afforded good specimens of inoceramus, echinites and most of the characteristic fossils. Professor Buckland and Dr. Boué have traced the chalk through Hanover and in the north of Brandenburg.

The *quadersandstein* which occurs round Dresden, is by some considered as of the same age as the chalk. Certainly its fossils show that it cannot be much older.

In Poland the chalk formation constitutes a line of hills running parallel to the Carpathians. It is finely exhibited at Cracow. It contains abundance of flints, affords the usual organic remains, and rests on a bed of green sand. Hence, passing by Lemberg, it appears to extend to Russia. Here it occurs in detached points on the north side of the Dniester, to the north-east of Zaleszyky, between the 25th and 28th parallels of longitude, east of London.

According to Dr. Clarke, hills of chalk occur at Kasankaiya on the Don, and the town of Bielogorod, signifying *white city*, is said to take its name from the white chalk hills in its neighbourhood; but Mr. Strangeways is of opinion that the supposed chalk of the Crimea is really a tertiary formation, and that the localities on the Dniester are the only ones which are well ascertained in Russia.*

In Ireland a remarkable deposit of indurated chalk forms the basin of the great basaltic area in the north-east angle of the island. It contains flints and the same organic remains as the English chalk.

It would seem, as has been observed by Buckland and Conybeare, that the induration of the Irish chalk has been owing to the action of the trap rocks connected with it, which were probably in contact with it while in a state of fusion.

In Italy the Scaglia, which covers the extreme secondary chains of the Alps in the Veronese is considered as a variety of chalk. It leans against the group of the Euganean hills, near

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* Geological Transactions (second series), i. 1.

the mouth of the Po, which appear to have forced it upwards. Like the Irish chalk it is indurated, and, doubtless owing to the same cause, being partially covered by the extinct volcanoes constituting the Euganean hills.

According to Dr. Boué, chalk occurs also in the basin of Bohemia and the valley of the Elbe. The formation in this district known by the name of *planer kalk*, is, according to him, really chalk. He notices scattered patches of it in the valley of the Elbe, in the bottom of a sinuosity in the granite near Mahles on the east of Meissen; between Plauen and Strehlod, west of Dresden; and near Zchist, south of Pirna.

The basin of Suabia and Bavaria appears to exhibit cretaceous marls and chloritous chalk, like that of Bohemia, on its southern border at the foot of the Alps. As, for example, south of Munich, at Berg, and near Gastein.

I am not aware that chalk has been met with in America, either on the north or south side of the Isthmus of Darien, nor has it been observed in any part of Africa or Asia.

CHAP. IX.

OF THE GREEN SAND FORMATION.

The formation immediately under the chalk has been denominated *green sand* (*glaucinie* by the French), in consequence of the green-coloured particles frequently visible in its uppermost bed. In Sussex and Kent where this formation is most fully developed, and where it has been most carefully studied, it consists of four subordinate formations, which have been distinguished by the following names, beginning with the uppermost.

1. Upper green sand, called also firestone and Merstham beds.
2. Galt or blue chalk marl.
3. Lower green sand.
4. Weald clay or ferruginous clay.

1. The *upper green sand* is a bed directly under the chalk marl. It consists of marl mixed with green-coloured grains, which, according to the analysis of Berthier, are composed of

			Atoms.
Silica,	50	25	16
Protoxide of iron,	21	4·6	3
Alumina,	7	3·11	2
Potash,	10	1·66	1
Water,	11	9·77	6
	99		

Hence its constitution is $KS^3+3fS^3+2AlS^2+6Aq$.

In some places this formation is in the state of sand, while in others it constitutes a stone sufficiently hard for building, and called in the country *firestone.*[*] The transition from the marl to the firestone, is in many localities so gradual, and the sandy particles are so sparingly distributed, that the *chalk marl* may be said to repose immediately on the *galt.* In other places, however, the characters of the firestone are very peculiar, so much so, that some geologists have deemed them sufficiently important to rank as an independent formation.

It may be seen very well exposed at Southbourn, a little to the east of Beachyhead, where it lies immediately under the chalk marl.

The fossils discovered in this bed, are, with but few exceptions, similar to those which are common in the chalk marl, namely,

Ammonites varians,
———— Mantelli,
———— planulatus,
Turrilites,
Scaphites,
Grypheæa vesiculosa,
Echinus Murchisoni,
Fucoides Targionii.

In attempting to trace this bed through the interior of the country, we find its course in many localities but obscurely indicated; and in some, the prevalence of a few green particles in the lower beds of chalk constitutes the only evidence of its existence.

2. Immediately under the upper green sand lies a bed of stiff marl, varying in colour from a light grey to a dark blue, and abounding in marine shells, and called *galt* or *gault,*[†] from a provincial term used in Cambridgeshire. It generally constitutes a valley within the central edge of the chalk of Sussex, Hampshire, Surrey, and Kent, and may be traced with little interruption from Southbourn to Folkstone, in Kent, near

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[*] *Macigno crayeux* of Brongniart.

[†] *Marne bleue de la glauconie* of Brongniart.

which town it forms a cliff, celebrated for the beauty and variety of its organic remains.

It forms a soil remarkable for its tenacity, and is usually distinguished by the term *black land*. It seldom exceeds 100 feet in thickness. It may be traced with little difficulty from near Loughton Place, six miles north-east of Lewis, almost round the amphitheatre of chalk hills which encloses the Wealds of Kent and Sussex, and always under the upper green sand where that bed can be distinguished. In the more northern and western chalk districts the galt bed is not so distinct. In Cambridgeshire it is called *galt*, in Surrey, *malm*.

The fossils in this bed are remarkable for their beauty, the pearly covering of the shells being generally preserved. They consist of

Ammonites,
Hamites,
Nautili,
Belemnites,
Nuculæ,
Inoceramus, sulcatus, concentricus,
Turbinolia,
Caryophyllia.

The crustacea in the galt are but few. Some of the most remarkable have been figured by Mr. Mantell. They are

(1.) A species of a new genus of the family *Leucosiadæ*, nearly related to the genus *Arcania*. The shell, or crust of the thorax, alone remains. It is of a suborbicular form, rather inflated, obscurely trilobate, with 12 or 13 aculeated tubercles. The margin is dentated.

(2.) A species of a genus of the family *Carystidæ*. The shell is oblong, ovate, depressed; the surface covered with minute granulæ, the margin bidentated near the front. No vestiges of the legs, antennæ or claws remain.

(3.) A species of the genus *Etyus*, of the family *Canceridæ*. Transversely obovate, obscurely trilobate; the surface covered with irregular papillæ.

(4.) A species of a genus belonging to the family *Coristidæ*, intimately related to *Corystes*. This species is longitudinally obovate, convex, with a tuberculated dorsal ridge, having a row of three tubercles on each side. The shell is truncated posteriorly, and the margin literally tridentated. The abdomen is composed of six or seven arcuate segments, and there are three or four legs on each side.

(5.) Fragments of the abdomen of two species of *Astacidæ*.[*]

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[*] See Mantell's Geology of the South-East of England, p. 166.

3. *Lower green sand.* This formation is also called *shanklin sand*, because it is very conspicuous at Shanklin, on the east side of the Isle of Wight. It consists of sands and sandstones, of various shades of green, grey, red, brown, yellow, and white, with subordinate beds of chert, limestone, and fuller's earth. These beds are but obscurely seen in the east of Sussex; but as we proceed towards the west they gradually rise into hills of considerable altitude, and form a striking feature in the physical geography of the country. These beds admit of a triple division, as was first shown by Dr. Fitton.*

The first or uppermost consists of sand with irregular concretions of limestone and chert, sometimes disposed in courses oblique to the general direction of the strata. The top of this sand in the vicinity of Folkstone and Hythe, forms an extensive plateau, resembling that of the Blackdown range of hills in Devonshire.

The second consists chiefly of sand, but in some places is so mixed with clay, or with oxide of iron, as to retain water. It is remarkable for the great variation in its colour and consistency.

The third and lowest group abounds much more in stone; the concretional beds being closer together and more nearly continuous.

In the south-eastern parts of Sussex, this formation occupies but an inconsiderable extent on the surface, and in many instances, a few insulated hillocks are the only indications of its presence. In Kent and Surrey, the lower green sand occupies a more considerable space, Hythe, Maidstone, Sevenoaks, Tilvester hill, Riegate, and Godalmine, are situated in it. In the Isle of Wight, it constitutes a very considerable portion, interposed between the chalk hills which traverse that island towards the north and the undercliff on the south. Shanklin and Sandown bay constitute its termination on the east. In the other parts of England, near the chalk hills, it has not been so accurately distinguished.

The only remains of the higher animals hitherto found in this formation, are a few teeth of fishes, both of a conical and lanceolated shape. The shells are very numerous. A pretty copious list of them has been given by Mr. De la Beche, in his Manual of Geology.†

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* Annals of Philosophy (2d series), viii. 365.

† Page 303.

In Parham park, casts of univalves and bivalves, particularly of trigoniæ, gervilliæ, and rostellariæ, are found in perfection in the indurated blocks of ferruginous sand. Many new species have been discovered by Mr. Martin in the middle and lower group of sands in the vicinity of Pulborough. Among these are

Mya mandibula,
Trigonia spinosa,
Nucula impressa,
Mytilus edentulus,
Pholadomya,
Lenia,
Lucina,
Modiola, &c.

4. *Weald clay.* The term wealden was suggested by Mr. Martin, to designate the strata which, in the south-east of England, are interposed between the lower arenaceous beds of the sand formation and the Portland oolite.

Taken in a general view, this formation may be considered as a series of clays and sands with subordinate beds of limestone, grit, and shale, containing fresh water shells, terrestrial plants, and the teeth and bones of reptiles and fishes; univalve shells prevailing in the upper, bivalves in the lower, and saurian remains in the intermediate beds. The state in which the organic remains occur, showing that they have been subject to the action of river currents, but not to attrition from the waves of the ocean. The district of this formation may be described as an irregular triangle, the base extending from near Pevensey in Sussex, to Seabrook in Kent, and the apex being situated in Western Sussex, near Harting Combe.

Mr. Mantell has divided this formation into the three following subordinate ones.*

1. *Weald Clay.*

It constitutes a stiff clay of various shades of blue and brown, with subordinate beds of limestone and sand containing septaria. The fossil remains in it are

Poludinæ,
Cypris faba, cyclides,
Bones of reptiles, rare,
Scales and bones of fishes.

It may be seen in the Wealds of Sussex, Surrey, and Kent, forming the vale between the Downs and the Forest ridge.

2. *Hastings Beds.*

a. *Horsted Sand.*

Grey white, ferruginous, and fawn-coloured sand and fria-

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* Geology of the South-East of England, p. 182.

ble sandstone, with abundance of small portions of lignite. This sand contains traces of carbonized vegetables.

b. *Strata of Tilgate Forest.*

Sand and *friable sandstone*, of various shades of green, yellow, and ferruginous; surface often deeply furrowed.

Tilgate stone, very fine compact, bluish or greenish grey, grit, in lenticular masses, surface often covered with mamillary concretions; the lower·beds frequently conglomerate, and containing large quartz pebbles.

Clay or *marl*, of a bluish grey colour, alternating with sand, sandstone, and shale.

The fossils are rarely bones and shells, ferns, and stems of vegetables.

c. *Worth Sandstone.*

White and yellow friable sandstone and sand. The fossils are ferns and arundinaceous plants, lignite, &c.

3. *Ashburnham Beds.*

A series of highly ferruginous sands, alternating with clay and shale, containing ironstone and lignite. The fossils are ferns and carbonized vegetables.

Shelly limestone, alternating with sandstone, shale and marl, and concretional masses of grit.

The fossils are Cypris; shells of the genera cyclas and cyrena; lignite and carbonized vegetables.

1. *Weald clay.* This formation is remarkably favourable to the growth of the oak. Its out crop forms a valley between the lower green sand on the one hand, and the forest ridge on the other, throughout the northern and north-western division of the southern denudation of the chalk. But in the south-eastern part of Sussex, where the lower green sand is scarcely seen on the surface, it constitutes a valley at the foot of the northern escarpment of the Downs, its beds of limestone and sandstone forming longitudinal ridges.

The Sussex marble, so strikingly characteristic of the Weald clay, occurs in layers that vary from a few inches to a foot or more in thickness, and are separated from each other by seams of clay, or of coarse friable limestone. It is of various shades of bluish-grey, mottled with green and ochre yellow, and is composed of the remains of fresh water univalves, formed by a calcareous cement into a beautiful compact marble. It bears a high polish, and is elegantly marked by sections of the shells which it contains. Occasionally a few bivalves *(cyclas)* occur, and the remains of the minute crustaceous coverings of the *Cypris faba* very constantly.

It is frequently found in blocks or slabs sufficiently large for sideboards, columns, or chimney pieces, and few ancient residences in Sussex are without them. They were used in the time of the Romans; and in the early Saxon times they were placed in the upper arcades of Cathedral churches, as at Canterbury and Chichester. Another general use was for the slabs of sepulchral monuments. Most of the principal Gothic edifices in England contain slabs or pillars of Sussex marble.

The shells in it belong to the genus *paludina*, the recent species of which inhabit fresh water. The remains of the *Cypris faba* are found also in a fresh water limestone in France. Sussex marble has been found in almost every part of the Weald clay.

The following table, drawn up by Mr. Mantell,* exhibits the most remarkable fossils found in the Weald clay:—

Fossils.	Localities.
Scales and bones of fishes apparently of a very small species.	Resting-oak hill.
Bones of saurians.	
Tooth of crocodile.	Swanage bay, Isle of Wight.
Cypris faba.	In the marble and septaria.
Paludina fluviorum.	In the marble.
———— extensa.	Ibid.
———— elongata.	Resting-oak hill.
Cardium turgidum.	Swanage bay.
Melanea attenuata.	Ibid.
———— tricarinata.	Ibid.
Cyclas membranacea.	Resting-oak hill.
Pinna.	Swanage bay.
Venus.	Ibid.
Potamides?	Shipley, near Cowfold.

2. *Hastings beds.* The alternating sands, sandstone and shale which form the central group of the Weald are distinguished by Dr. Fitton by the name of *Hastings beds*, because the cliffs in the neighbourhood of Hastings present the most instructive and extensive section that can be obtained.

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* Mantell's Geology of the South-east of England, p. 188.

They extend from Bexhill, in Sussex, to Ham Street, near Aldington, in Kent, forming a line of irregular cliffs about 40 miles in length, and from 20 to upwards of 600 feet in height. Crowborough hill, near Tunbridge Wells, which is the highest point in the range, is 804 feet above the level of the sea.

The Tilgate beds consist of irregular alternations of sand and sandstone, and lie immediately under the Horsted beds. The lowermost stratum of these contain large concretional or lenticular masses of a compact calciferous grit or sandstone, which was formerly quarried in the neighbourhood of Tilgate and St. Leonard's forests, near Horsham. These strata were first described by Mr. Mantell in 1822. There are three or four layers of the Tilgate stone varying in thickness from two inches to two feet each. They rest on blue clay and shale, which separate them from the next subdivision. They are the principal repository of the Saurian remains of the waters which deposited the Hastings sands, and are therefore by far the most interesting strata of the formation. They extend from its western extremity at Loxwood, to Hastings, where they occupy the upper part of the cliffs.

The blue clay which supports the Tilgate beds is succeeded by a series of arenaceous strata, some of which afford a fine soft building stone, which is extensively dug at Worth, near Crawley. It is for the most part of a white or fawn colour, and occasionally contains leaves and stems of ferns and other plants. The Worth sands occur in great force at Hastings, occupying the middle of the cliff.

3. The Ashburnham beds occupy the base of the cliffs at Hastings, and appear in many places in the interior. They are succeeded by beds of shelly limestone, alternating with shale, and including layers of a fine grit, precisely similar to the Tilgate stone. This bed abounds with carbonized vegetables *(ferns)*, casts of bivalves and other organic remains.*

Mr. Mantell has described and figured the principal fossils, both vegetable and animal, found in the Wealden strata. Indeed, for the knowledge of not a few of these fossils we are indebted to Mr. Mantell himself. The principal vegetable impressions are of the following plants:—

1. The petrified trunks of large plants, belonging to that tribe of vegetables which is so common in the coal beds, and

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* For a minute description of the different Wealden strata, the reader is referred to Mr. Mantell's *Geology of the South-East of England*, which is chiefly occupied with an account of these interesting beds.

which seem to hold an intermediate place between the Equiseta and the Palms. Of these the most interesting is the

Clathraria Lyellii, figured by Mr. Mantell in his first plate.
Endojinites erosa, also figured by Mantell in his first plate.
2. Cycadites Brongniarti, figured by Mantell, p. 238.
Sphenopteris Sillimani, } Figured by Mantell, p. 239.
———— Phillipsii, }
———— Mantelli, Ibid. p. 241.
Lonchopteris Mantelli, Ibid. p. 243.
Lycopodites?
Calamites?
Equisetum Lyellii, Ibid. p. 248.
Carpolithus Mantelli, Ibid. p. 246.

The shells described by Mantell are:—

Paludina elongata,
———— carinifera,
———— fluviorum,
Neretina Fittoni,
Psammobia,
Cypris fabà.*

Cyclas membranacea, }
———— media, } Mantell, p. 249.
Melanopsis, or Melanca, }
Unio antiquus, }
——— compressus, } Ibid. p. 250.
——— aduncus, }
——— porrectus, }
Psammoben, Mantell, p. 248, fig. 6.
Mytilus.

The remains of fishes in the Wealden beds consist of detached bones, teeth, scales, and fins. In some rare cases the scales and skeleton lie in juxta position. These are referred by Mantell to the

Lepisosteus Fittoni.

The remains of various species of turtles, both fresh water and marine, have been discovered in the strata of Tilgate Forest.

Teeth of the crocodile have been found in Tilgate Forest. They are figured by Mantell, p. 261.

Scales resembling those of the alligator.

Megalosaurus Bucklandi.

Iguanodon. The teeth, vertebræ, and horn of this animal were discovered by Mr. Mantell in the coarse conglomerate of the forest as early as 1822, and he has given an interesting

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* All figured by Mantell, p. 248.

account of the remains of this extraordinary reptile, which seemingly fed upon vegetables.* Nothing like a perfect skeleton of this remarkable animal has hitherto been found.

Plesiosaurus, probably *dolichodeirus*, the same as occurs in the *lias.*

Bones of a bird, probably of a species of *ardea.*

Megalosaurus. Teeth.

Cylindricodon. Teeth.

Hylæosaurus.†

Traces of the *green sand* formation may be observed underying the escarpments of chalk in Yorkshire. It appears very decidedly in the vale of the *white horse* in Berkshire, near Childray and Wantage. Hence it may be traced through he counties of Wilts and Dorset. In Wiltshire it frequently onstitutes a secondary range of hills standing in advance of hose of the chalk formation, and nearly rivalling them in eight. This is the case at Warminster and Stourhead. It orms also the vales of Pewsey and Wardour.

On the confines of Dorset and Devon, it presents many igh and insulated masses, constituting outliers. In this way t forms the extensive table-land of Blackdown, which stretches ar into the west, covering a great part of the eastern district of Devonshire. Still farther west and beyond Exeter we have another outlying mass of this formation, capping the ong range of Haldon Hill, which is divided only by an inermediate valley from the granite of Dartmoor.

On the continent the green sand formation may be seen on he coast of France opposite to Kent. The western boundary is near Havre and Honfleur, and the eastern boundary at Valenciennes, where the green sand assumes a conglomerate character, and is known by the name of *Tartia.* This tract has been described by Omalius d'Halloy under the name of *ower chalk.*

On the northern borders of the Alps, the highest beds of he exterior calcareous chain consist of a dark coloured limestone, often mixed with sand and green particles, and agreeing n its fossils with the green sand formation in England. Similar beds, and in a similar position, are described as occurring on the skirts of the Maritime Alps of Nice.

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* P. 269. See also Phil. Trans., 1825, p. 179.

† An interesting description (with figures) of the skeleton of this animal, discovered by Mr. Mantell in the sandstone of Tilgate Forest in 1832, will be found in his work so often referred to, p. 331.

The *quadersandstein* of Saxony is considered by some to belong to the green sand formation; but the more general opinion is that it constitutes a bed in the oolite formation.

M. Thirria describes a considerable superficial deposit of clay with pisiform iron ore in the department of the Haute Saone, part of which he considers as referrible to the green sand.

M. Brongniart notices among the cretaceous rocks of the Isle d'Aix, and the embouchure of the Charenti, a marl which he refers to the Wealden clay, containing nodules of amber, pieces of lignite, and silicified wood, in which holes formed by some perforating animal are replaced by agates.*

According to Professor Pusch, there is a ferriferous deposit in Poland, situated between the Jura limestone and the cretaceous rocks, which may be considered as the equivalent to the Weald clay and iron or Hastings sand of England. He gives a detailed description of this formation in the second volume of the *Journal de Géologie.*

The fossil plants hitherto met with in the green sand amount only to seven species. Of these five species are monocotyledonous, namely, four species of *zosterites* and one species of *clathraria.* Two species are ferns, namely one species of *sphenopteris* and one of *lonchopteris.*

CHAP. X.

GREAT OOLITE FORMATION.

THIS formation is of great importance, not only on account of the space which it occupies, and the numerous beds of which it is composed, but because it was first made out in all its subdivisions in Great Britain. For this most important step in geology we are in a great measure indebted to the sagacity of Mr. Smith, who first determined the beds, pointed out their distinguishing characters, and even distinguished them by name.

This formation begins in Yorkshire, a little to the south of the Tees, and extends southwards along the sea coast as far as the Wash in Lincolnshire, a breadth of about ninety miles.

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* Tableau des Terrains, p. 217.

But in the interior of the island its breadth scarcely exceeds thirty miles. From the sea coast of Yorkshire it passes in a south-westerly direction to the south of England, and reaches the sea on the coasts of Devon and Dorset, its western extremity being not far from Sidmouth, and its eastern the Isle of Purbeck, constituting a breadth little short of forty miles.

This great tract of country is composed of a series of oolitic limestones, of mixtures of sand and limestone, of clay and marly beds alternating with each other, and generally repeated in the same order. When we cross over this formation, travelling from south-east to north-west, we may observe, that it consists of three series of low hills running parallel to each other, and separated by considerable valleys. These three chains naturally divide the formation into three parts or systems, which are distinguished by the names of

1. Upper oolite.
2. Middle oolite.
3. Lower oolite.

The three intervening valleys are occupied by clays, or calcareous clays, which are distinguished by the names of

1. Kimmeridge clay.
2. Oxford clay.
3. Lias limestone.

This great formation is remarkable for the numerous fossils which it contains.

Impressions of no fewer than 43 species of plants have been enumerated. Of these 27 are cryptogamous plants, namely, 22 ferns and 1 equisetaceous species, 1 lycopodiaceous, and 3 fucoides; 4 are *cycadeæ*, 1 Bucklandia, 9 coniferæ, and 2 not well determined. Two of these, namely,

Zamites Bechii,
——— Bucklandi,

have been observed at Lyme Regis, in Dorsetshire.

20 have been observed in the coal beds near Whitby, which occur in the lias, the lowest bed of the great oolite formation. 8 have been met with in the same beds at Här, in Sweden, and 4 in Bornholm. The most remarkable of these are the following:—

Glossopteris Nelsoniana,	Lycopodites patens,
Pecopteris Agardhiana,	Culmites Nelsonii,
Clathropteris meniscoides,	Pterophyllum dubium,
Tæniopteris vittata,	Nelsonia brevis.*

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* An interesting description of the vegetable fossils in the coal beds in

The remaining vegetable impressions have been observed at Neuewelt Stutgard, or in France.

In the undermost beds of this formation corals are rare, one tribe only, the turbinolia, having been met with. But several species of pentacrinite and echinus occur in the lias limestone.

Higher up in the series among the oolite limestones, we meet with alcyoniæ and a variety of corals. Indeed there is one bed almost entirely composed of corals, and on that account distinguished by the name of *coral rag*. The crinoid family is rather conspicuous in the oolite. Among others may be mentioned the *pentacrinites caput Medusæ* and *subangularis*. Species of the genera *conulus*, *cidaris*, *echinus*, and *clypeus* of the echinus family are met with, and more rarely, fragments of crustacea.

A very considerable number of shells, both univalves and bivalves, occur in this formation. A list of 199 species, together with the localities where each was found, has been given by Brongniart in his *Tableau des Terrains*. But by far the most complete list is given by De la Beche in his Manual of Geology. He enumerates 42 species of plants, 327 species of zoophites, 748 species of shells, 34 species of reptiles, besides several insects and fishes whose species have not been determined.

The remains of fish are not uncommon in the lower beds of this formation, but they are always in a very imperfect state. I am not aware that any of them has been referred even to a genus, except the *Dapedium politum*, described by De la Beche as occurring at Lyme Regis.

In this formation the bones of several oviparous quadrupeds make their appearance, and no quadrupeds are met with lower down in the series. They consist mostly of the remains of amphibious quadrupeds, which are capable of living both on land and in water. These are the remains of turtles and of various species of animals belonging to the genus lizard, but differing in structure from all the species at present known to exist, and in such particulars as must have fitted them to live entirely in the sea. These are the *Ichthyosaurus*, *Plesiosaurus*, and *Megalosaurus*. The last must have been an animal of prodigious size. A skeleton of one, 40 feet long, has been found at Stonefield.

the south of Sweden, which seem to belong to the lias formation, may be seen in the Kŏng. Vet. Acad. Handl. for 1823 and 1824.

Four species of Ichthyosaurus have been found at Lyme Regis, namely,

Ichthyosaurus communis,
———— plytyodon,
———— tenuirostris,
———— intermedius.

The plesiosaurus dolichodeirus has been met with at the same place. And the

Plesiosaurus carinatus,
———— pentagonus,
———— trigonos,

have been found in the north of France.

The bones of a well characterized crocodile have been met with at Boll in Wirtemberg, namely, the *crocodilus Bollensis*. It has been met with also in England. It is a different species from any of the crocodiles at present existing.

But the most singular fact is the occurrence of the bones of a species of didelphis, or opossum, in the Stonefield slate near Woodstock, in Oxfordshire. The opossum tribe has been observed only in America and New Holland, and never in any part of Europe, Asia, or Africa.

The Stonefield slate, so abounding in curious petrefactions, contains also legs and thigh bones, apparently belonging to birds. But even the genus to which they belong has not been determined.

Two or three species of coleopterous insects (at least so pronounced by Dr. Leach) have been met with also in Stonefield slate. In the same slate occur several vegetable impressions, principally flags, ferns, and mosses. The most characteristic shell in the Stonefield slate, is a small studded *trigonia*.

From these petrifactions, there can be little doubt that the great oolite formation was formed at the bottom of the sea. At the time of the deposition of the beds, the sea was inhabited by fishes and zoophites. It would appear also, that some enormous amphibious animals, now extinct, at that time existed.

The great oolite formation, then, marks a remarkable era in the history of the earth—the period when amphibious animals began to exist, and when the opossum tribe, and also birds, began to make their appearance. We must now take a more particular view of the different beds of which this great formation is composed.

1. *Upper Oolitic System.*

This subdivision of the oolite may be divided into three subordinate formations; namely,

1. Argillo-calcareous strata of Purbeck, which constitutes the highest of the oolitic series.
2. Oolitic strata of Portland, Tisbury, and Aylesbury.
3. Kimmeridge clay—Oaktree clay of Smith.

(1.) The Purbeck beds, so called, because they are best seen at Purbeck in Dorsetshire, to the west of the Isle of Wight, consist of many thin strata of argillaceous limestone, alternating with slaty marls, and forming an aggregate of more than 300 feet in thickness.

The Purbeck stone consists chiefly of shells (principally the helix vivipara), partly whole and partly in a state of comminution, imbedded in a calcareous cement, which is sometimes very pure and crystallized, and sometimes in a state approaching to indurated marl. These beds are separated by others entirely without shells, and also by layers of shale and marl, the shivery nature of which allows the stone to be quarried with great ease.

The stone well known by the name of Purbeck marble, and which was formerly much used in the Gothic churches in the south of England, for columns and monuments, was nearly the uppermost of these beds, and differs from the common Purbeck stone only in the purity of its calcareous matter, and in the shells being more entire. It is almost identical with the Petworth marble, but is now out of use, and the quarries are filled up and scarcely known.

Beautiful impressions of fish are frequently met with by the quarrymen, between the laminæ of the limestone, and abundance of fragments of bones, some of which belong to the turtle. Mr. Johnson of Bristol, possesses a very perfect head of a crocodile found in Purbeck, but it is not quite certain whether it belongs to the Portland or Purbeck beds.

The thickness of the beds at Purbeck is about 291 feet. And the greatest thickness of the upper oolitic system is about 1011 feet.

The Portland beds first make their appearance in Buckinghamshire. They appear very conspicuous in the upper part of Shotover hill, near Oxford, immediately under the Hastings or iron sand, which constitutes the summit of the hill. At the foot of the ridge, at Shotover, the Kimmeridge clay makes its first appearance near the village of Headington.

The beds may be traced south till they are lost by a thick covering of chalk in Wiltshire. On the south side of the chalk, an opening between Stourhead and Shaftesbury again exposes the subjacent strata. From this they may be traced till they terminate on the sea coast, in the isles of Portland and Purbeck, which constitute the southern extremity of Dorsetshire. At Fonthill, Chilmark, and Tisbury, these beds have been much disturbed, and instead of their usual horizontality, have been greatly raised, and dip to the north and east at an angle of 40°.

(2.) The second member of the higher oolitic system is the Portland stone. This formation consists of several beds of coarse earthy limestone. The different beds often vary in their characters; nor are the same beds of an uniform texture in different localities.

The calcareous rocks are most commonly a fine-grained white oolite, or a loose granular limestone of earthy aspect, and of various shades of yellowish-grey; and more rarely a compact cretaceous limestone, having a conchoidal fracture. In Wiltshire and Dorset, many of the beds contain layers of chert, alternating with them, like the flints, in the chalk formation. The lower beds are very sandy and often very abundant in green particles.

The more oolitic varieties, principally quarried in the Isles of Purbeck and Portland, afford most of the stone used in London for architectural purposes.

The uppermost beds in the Isle of Portland, consist of an oolitic rock, and they are numerous. That which appears on the summit, and is called the *cap*, is of a yellow colour and porcellaneous character. It is only burnt for lime. The next bed is worked for sale, being the best building stone. Those below this bed contain numerous casts of shells that injure the stone, which is only used for coarser purposes; and with these beds others alternate, consisting of chert.

The whole thickness of these beds is about 120 feet.

The remains of fish are occasionally met with in the Portland beds. The following table exhibits a list of the principal shells occurring in this formation:—

Ammonites triplicatus,
———— giganteus,
———— Lamberti,
———— Nutfieldiensis,
Turritella,
Natica,
Solarium conoideum,
Trochus,
Ostrea expansa,
Crenatula,

Pecten lamellosus,
Trigonia clavellata,
——— gibbosa,
Astarte cuneata,
Lutraria ovalis,
Nerita sinuosa,
Unio,
Cardita,
Cyclas,
Venus.*

Of these shells the Ammonites triplicatus, and pecten lamellosus, are most characteristic.

No other zoophitical remains are mentioned, than those of a beautiful aggregated madrepore, specimens of which, imbedded in a semitransparent chert, occur at Tisbury in Wilts. Large fragments of wood are common.

(3.) *Kimmeridge clay.* The beds of this formation consist of a blue slaty or greyish-yellow clay containing selenite. But it sometimes contains beds of highly bituminous shale; as, near Kimmeridge, on the coast of the isle of Purbeck, where it is used as fuel, and has obtained the name of *Kimmeridge coal.* The beds are finely displayed near that place. They are also well exposed on the coast of the isle of Portland.

Near Smedmore, in the parish of great Kimmeridge, is found, what the country people call *coal money*, generally on the top of cliffs, two or three feet below the surface, enclosed between two stones set edgeways, and covered with a third. Along with the coal money, there is always the bones of some animal. The pieces called coal money, are from two to three inches and a half in diameter, and a quarter of an inch thick; round, on one side flat and plain; on the other, convex with mouldings. On the flat side there are two, sometimes four, small holes, probably the central holes by which they were fixed to the turning lathe. They are supposed to have been either *amulets* or *money.* There has also been found in the neighbourhood, a shallow bowl of Kimmeridge coal, six inches high and as many in diameter, containing coal money.

The Kimmeridge clay beds, where thickest, which is on the shore of the isle of Purbeck, are about 600 feet in thickness; but they thin out as we proceed north. Near Oxford the beds are only 100 feet thick. Farther north they disappear altogether.

Remains of the ichthyosaurus and plesiosaurus have been found in this formation, at Kimmeridge and Headington. The shells observed in it are the following:—

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* Conybeare and Phillips' Geology of England and Wales, p. 175.

Nautilus,
Ammonites, 5 species,
Belemnites,
Trochus,
Turbo,
Melania Headingtoniensis,
Ostrea deltoidea,
——— cristagalli, and three other species,
Astarte lineata,
——— ovata,
Trigonia costata,
Trigonia clavellata,
Venus,
Modiola,
Cardita,
Cardium,
Mactra,
Tellina,
Chama, 2 species,
Avicula,
Pecten,
Terebratula,
Serpulæ.[*]

Of these shells, the ostrea deltoidea appears to be the most characteristic. The water in this formation is deficient, and of bad quality.

2. *Middle oolitic system.*

The thickness of the congeries of beds, which constitutes the middle oolitic system, is between 500 and 600 feet. It constitutes the second range of hills, together with the valley situated between that range and the third range of hills. Like the preceding, it may be divided into three subordinate beds; namely,

1. Coral rag,
2. Calcareous sand and grit,
3. Oxford clay, or clunch clay of Smith.

It will be more convenient to consider the first two of these beds together, as they are, in fact, intermingled. They constitute a series of beds, occupying a thickness of from one to two hundred feet; in the upper part of which, the calcareous matter, and in the lower, the siliceous, prevails.

The *coral rag*, properly so called, occurs principally towards the middle of the series. Such, at least, is the disposition of the beds near Oxford, where they have been most attentively examined. And it has been ascertained, that the same order prevails in Wiltshire.

The *upper calcareous beds*, are a calcareous freestone, of tolerably close texture, full of shells comminuted into fragments, generally too small to admit the determination of the genus; more or less oolitic, frequently very indistinctly so; but occasionally passing into beds, in which the oviform grains

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[*] Conybeare and Phillips' Geology of England and Wales, p. 178.

are much larger than in any of the other oolites. The colour of all these beds is of a yellowish white, becoming palest in the most oolitic, and passing occasionally into shades of light grey. It affords a tolerable building stone, but far inferior to the oolites of the uppermost and undermost systems. Oxford has to regret her vicinity to this formation, as it has had rather an injurious effect upon the beauty and durability of her splendid buildings. It is a tolerable limestone, but contains from one-tenth to one-third of sand.

The coral rag which lies under this freestone, consists, as its name imports, of a loose rubbly limestone, mingled with, and often almost entirely made up of, a congeries of aggregated and branched madrepores. Two or three irregular courses of this rock intervene between the freestone and the inferior sandy beds. They often assume a marly character, and grey colour: they are used for lime, and for mending the roads.

The sandy, or, rather, siliceo-calcareous beds, consist of a thick deposit of yellow-coloured quartzose sand, usually containing about one-third of calcareous matter, and traversed by irregular strata, and concretions of indurated calcareo-siliceous gritsone. These rest immediately on the subjacent Oxford clay, and may be traced through the whole escarpment of the hills composed of this formation, supporting the coral rag and freestones. It is in the calcareous grit of this sand that the fossils of this formation occur in the greatest plenty, and especially in the beds immediately beneath the coral rag beds. The *ostrea gregaria* characterizes the sand generally.

Iron is generally abundant throughout the sand; so much so, as frequently to give it a red colour.

This formation appears first on the east of Oxford, where it forms the elevated platform rising on the south-west of Otmoor, and occupying the interval between the confluence of the Charwell and Thame with the Isis. This platform supports the still higher ridge of Shotover hill, composed of the upper system of oolite. The whole of its surface, which extends about five miles from east to west, and seven from north to south, is covered with quarries, of which the principal are those of Headington, two miles east of Oxford, at the foot of the high ridge of Shotover, in which the junction of the beds of this formation, and the Kimmeridge clay, which lies above them, is well displayed.

This formation passes regularly from a little north of Oxford, as far south as Frome, in Somersetshire. It terminates a little to the east of that town, between the counties of Somerset and Wilts.

The remains of vertebral animals are scarce in this formation. Yet vertebræ of the Ichthyosaurus have been found in its beds of calcareous grit. The shells are numerous, especially in the beds of calcareous grit. The following are the principal:—

Ammonites, 5 species,
Nautilus,
Belemnite,
Melania,
Turbo muricata,
Helix,
Trochus bicoronatus,
Ampullaria,
Turritella,
Serpula,
Ostrea gregaria, cristagalli,
Pecten fibrosus,
Chama,
Trigonia,
Lima rudis,
Lithophaga,
Mytilus,
Modiola.

Fragments of fibrous shells are common, but not sufficiently perfect to be made out. Many beautiful echinites occur in this formation. The most remarkable of which are

Cidaris, 3 species,
Clypeus, 2 species.

It is in this formation that the clypeus first appears, never being found in any formation situated above it.

Madrepores are abundant in this formation; but in those above it they are few and scarce. The chief are

Caryophyllia, 2 species,
Astrea, 3 species.

Fossil wood is often found in the calcareous grit belonging to this formation.

(3.) The *Oxford* or *clunch clay* forms the valley which separates the middle oolite from the inferior range. It includes subordinate beds of limestone, called Kelloway rock.

It consists of very thick beds of a tenacious and adhesive clay, of a dark blue colour, becoming brown on exposure, and containing argillo-calcareous geodes and septaria. These latter are often called *turtle stones*. The clay beds are often mixed with calcareous, and sometimes with bituminous, matter, affording, in the latter case, an inflammable shale, which has led to various unsuccessful searches for coal.

In 1787, this formation was bored through near Boston, in Lincolnshire, in sinking a well. It was 478 feet thick. At the village of Donnington, six miles west of Louth, in Lincolnshire, it was penetrated to the depth of 309 feet, in search of coal. The beds were forty-one in number, and consisted of alternations of clay, bituminous shale, and ironstone. In some beds the clay was indurated, in others soft.

The lower portions of the formation occasionally contain irregular beds of limestone. These have been noticed chiefly at Christian Malford, and Kelloway bridge, near Chippenham, in Wiltshire; and from the latter locality have been called *Kelloway rock.* This stone occurs in irregular concretions, the exterior aspect of which is brown and sandy; the interior being harder, and of a bluish colour. It consists almost entirely of a congeries of organic remains, among which several varieties of ammonite are predominant. The beds of clay which cover this rock, abound in selenite, and below it are found a brown aluminous earth, and bituminous wood. Beds of clay separate the Kelloway rock from the oolites.

This formation appears on the sea-shore at Yew Nab, near Filey bridge. It is probable that the greatest part of the clay vale lying along the Yorkshire Derwent, as far as New Malton, and lying between the chalk and the oolites, belongs to this formation.

South of the Humber it may be traced in a southern direction through Lincolnshire, following the course of the fens along the Ancholme navigation, and the Witham river to Boston. It forms the substratum of the western part of the Cambridgeshire fens, and those which border on Huntingdonshire. Hence it is sometimes called *fen clay.* Where it enters Lincolnshire on the north, it forms a very narrow tract, not more than three miles across. But in the southern part of that county it is a good deal broader, not less than 15 miles, which may be considered as its maximum breadth in England.

A line drawn from Peterborough to Bedford, Buckingham, and Bicester, nearly marks its junction with the subjacent oolite; and another from Huntingdon to Oxford, its superior junction. At Huntingdon its breadth is about 12 miles, and between Bedford and Oxford it is not more, on an average, than 5. West from Oxford it ranges along the valley of the Isis, as far as Cricklade. Thence bending on the east of Malmesbury, it traverses Wilts in a southern direction, following the course of the Avon past Chippenham to Melksam. It passes on, sometimes disappearing, and finally reaches the sea near Weymouth.

Throughout the whole of its course it is very low, though occasionally it rises into moderate heights, as near Buckingham and Bedford. Its average thickness is certainly not less than 500 feet.

In general it forms a poor soil, except when covered by white clay or chalk breccia. The vale from Melbury to Shaftesbury, in Dorsetshire, is famous as a butter country.

Bones of the Ichthyosaurus occur in Oxford clay; but they are rare, and of a different species from those in the lias. It contains also

Ammonites, 3 species
Nautili,
Belemnites,
Rostellaria,
Serpula,
Patella,
Ostrea,
Gryphæa,
Perna.

The petrifactions in the Kelloway rock are

Ammonites, 3 species,
Nautili,
Belemnites,
Rostellaria,
Cardita deltoidea,
Chama digitata,
Gryphæa incurva,
Pecten fibrosus,
Plagiostoma obscura,
Avicula inequivalvis,
Terebratula ornithocephala.

3. *Lower oolitic system.*

This is by far the thickest and most extensive of the three. The beds are very numerous, and many of them have been distinguished by peculiar names; but, as most of these are only subordinate to the great oolitic stratum, we may without impropriety subdivide it, as we have done the other two systems, into three great deposits. These are

1. Great oolite.
2. Calcareous siliceous sand.
3. Lias.

1. *Great oolite.* This name has been imposed by the English geologists, because the chain of hills formed of it may be considered as composed of one great oolitic mass, resting upon the calcareo-siliceous beds below it; but on a more minute examination it will be found, that the upper part of this great oolitic mass presents strata sufficiently distinct to entitle them to a separate description. These, instead of rising in thick masses, are generally fissile or rubbly, are much mingled with clay, forming as it were the link between the pure oolite and the Oxford clay above it. Instead of the yellowish tinge of the oolite, they have generally a blue

colour, or in some beds a pasty appearance, and a dead white colour not unlike chalk. It is impossible to trace any general division among these upper beds, which will apply to them in every part of the course of the great oolite. They appear rather as accidental varieties of this great formation. In some instances, indeed, the precipitates of argillaceous and calcareous matter appear to have followed each other alternately, at sufficient intervals to allow the formation of tolerably thick beds of either kind, which may be traced over pretty considerable tracts. This regularity is most distinguishable in the neighbourhood of Bath, and through an extensive tract in the neighbouring counties of Gloucester, Somerset and Wilts. Some idea may be formed of this part of the country by the following section in the neighbourhood of Tellisford and Farley Castle, ten miles south of Bath, beginning with the highest bed:—

1. Cornbrash, . . .	8 feet	to 16 feet
2. Clay, ...	8	14
3. Calcareo-siliceous sandstone,	40	10
4. Forest Marble, . .		18
5. Sand, ...		2
6. Clay, ...	20	60
7. Great oolite, . . .		130
		250

Let us take a view of the most important of these beds, some of which are of considerable importance.

(1.) The *cornbrash* is a loose rubbly limestone, of a grey or bluish colour; it rises in flattish masses, rarely more than six inches thick. The beds belonging to this stratum in Oxfordshire are often of a pasty or chalky consistence and colour. In Wiltshire it is known by the name of *Cornbrash* or *Corngrit*. At Malmsbury, where it is thick and solid, it is much quarried for building. In other places it is fit only for burning into lime, and for mending the roads.

The upper beds of stone which compose this rock, contain fossils materially different from those in the undermost beds. The clusters of small oystershells and the stems of the pentacrinus lie near together, and not many others are found near the bottom of the rock.

(6.) The *clay* bed lying over the great oolite is usually called *Bradford clay* by the English geologists, because it is best seen at Bradford upon the North Avon, a few miles east from Bath. It consists of a fine blue marly clay which, at the point of its contact with the great oolite, is replete with the remains of the *pear encrinus*, with many small coralloids, and several peculiar terebratulæ.

(3, 4, 5.) The 3d, 4th, and 5th beds are so intimately associated that they require to be described together. This assemblage consists of beds of limestone, generally fissile, and divided by argillaceous partings lying between two beds of calcareo-siliceous sand and gritstone. The undermost bed of sand is usually insignificant, though it sometimes swells into great thickness and importance. These sandy strata appear to contain about one-third of calcareous matter. The gritstone found in them is hard enough to scratch glass, and forms irregular slate-like concretions.

The limestone lying between these sands is called *Forest marble.* Its beds, generally speaking, are thin and slaty. Sometimes, however, beds of two or three feet thick may be found. The colour of the stone is generally gray or bluish, externally brownish, appearing on examination to be frequently composed of a congeries of dark-coloured shells interspersed with white oolitic particles. Bivalve shells are most common in the thick beds, and univalves in the thin. Decomposed pyritical wood often gives a partial redness, and some of the joints have a reddish tinge. The texture of the stone is coarse-grained—the structure of its masses fissile; whence, coarse roofing slates and flag-stones are in general use in the villages on the course of this rock. The more solid beds have been occasionally worked as a coarse marble, being susceptible of a tolerable polish, and variegated by the contour of its imbedded shells. From this circumstance, and the occurrence of these strata in Whichwood forest, Oxfordshire, it has derived its name.

The partings of the clay between the beds of this rock vary in thickness, from less than an inch to more than a foot.

The *calcareous slate of Stonefield* near Woodstock, Oxfordshire, belongs to the same part of the series as the forest marble. This slate is exceedingly remarkable for the singular variety of its organic remains, among which the spoils of birds, land animals and amphibia, occur mingled with vegetables and sea shells. The assemblage of beds worked at Stonefield, consists of two fissile strata of a buff-coloured or gray oolitic limestone called *pendle*, each about two feet thick, separated by a bed of loose calcareo-siliceous sandstone, called *race*, about the same thickness. Concretions are frequent in the *race*, which are called *whimstones* or *potlids*. They are partially oolitic, sometimes blue in the centre, and vary from six inches to two feet in diameter. Their form is generally that of a flattened sphere. They do not break concentrically, but into parallel planes, and they often contain shells.

The *pendle*, after being quarried, is suffered to lie exposed to a winter's frost, and the blocks being then struck on the edge with a mallet, freely separate into slates sufficiently thin to afford a light material for roofing. The quarries are principally situated in the valley immediately on the south of Stonefield village, which branches off eastwards from that of Evanlode.

In the Forest marble, though its various beds are composed of little else than a mass of shells, loose and whole specimens are rare, and are extracted with considerable difficulty. A few, however, are occasionally found in the clay between the layers of stone. Bones, teeth and wood, firmly imbedded in the rock, are some of its most characteristic indications. The following shells are stated by Conybeare to have been found either in the forest marble or the Stonefield slate:—

Nautilus,
A fusiform belemnite,
Patella rugosa,
Turritella,
Rostellaria,
Ancilla,
Serpula,
Trigonia costata,
Mya,
Venus?
Ostrea cristagalli,
Pecten fibrosus, and another species.

The fossil remains in the Stonefield slate are particularly deserving of attention. It constitutes the oldest rock in which the remains of land animals and birds occur. They consist of

An animal of the opossum tribe,
Crocodile,
Megalosaurus,
Ichthyosaurus,
Plesiosaurus.

The genus to which the birds belong has not been determined.

(7.) *Great oolite*. This bed, both in point of thickness and utility, is by far the most important of the British oolites. It consists of a stratified calcareous mass, varying in thickness from 130 to more than 200 feet. Softer and harder beds alternate in this mass of strata. The former affords the freestone employed for building, which renders the rock so valuable. These strata vary much both in thickness and quality, even in neighbouring quarries.

The Kettering freestone of Northamptonshire is rendered extremely beautiful by the distinctness of its oolitic structure. That of Bath has generally a finer grain; it has been employed in the late repairs of Henry VII.'s Chapel, Westminster. St. Paul's was built principally from quarries about a mile north of Burford in Oxfordshire.

Fragments of comminuted shells may be observed in all the varieties mingled with the ova, but so completely broken down that it is generally impossible to make out the species. This is the reason why we are so imperfectly acquainted with the fossils belonging to this rock.

The colour of the freestone beds is generally white, with a shade of yellow. Of the other beds some are grey, and some almost blue in the middle. Sometimes, also, beds of a brown rusty colour are interspersed, especially at the bottom of the series, near its junction with the fuller's earth. The freestone occurs in thickly bedded masses, which, if traced to a distance, will be often found to thin out. Many of the other beds exhibit a laminated cleavage not parallel to the greater lines of the stratification, for which they have sometimes been mistaken, and described as highly inclined beds alternating with horizontal ones.

The fossil shells in the great oolite are in general so shattered, that it is next to impossible to determine even the genus to which they belong. The only genera mentioned are ill-defined casts which have some resemblance to

Turbo,
Melania,
Ancilla,
Serpula,
Ostrea,
Pecten,
Terebratula,
Plagiostoma.

2. *Calcareo-siliceous sand.* This sandy deposit may be said to form the most universal and characteristic feature of this series; the sands pass almost insensibly by mixture of various loamy and marly beds towards their lower limit into the argillaceous formation which covers the lias; and towards their upper limit by an increase of calcareous matter into the lower oolitic beds. Between this lower oolite and the great oolite (also belonging to the lowest system), a thick calcareo-argillaceous formation, carrying beds of fuller's earth, and sometimes also beds of coarse oolite, is interposed, often forming a

very conspicuous division in this part of the series; though is frequently wanting altogether.

In the neighbourhood of Bath, the thickness of this calcar siliceous formation is about 220 feet. It consists of the following beds, beginning with the uppermost.

		Thickness.
1.	Calcareous sand, . .	50 + feet.
2.	Inferior oolite, . . .	30
3.	Bastard fuller's earth, .	100 +
4.	Good fuller's earth, . .	8
5.	Blue clay, . . .	15
6.	Yellow clay, . . .	15

The remains of vertebral animals are very rare in th beds. A series of vertebræ were discovered in the ma sandstone of Warkworth, Northamptonshire. They probab belonged to some saurian animal, but were dispersed witho having been determined, and none of them have been recover Fragments of the crab and lobster families have been d covered at Dundry, and in the north of Oxfordshire.

The distribution of organic remains is thus stated by Tow end:—"The lowest bed is distinguished by its abundant casts ribbed and studded Trigoniæ; immediately over this is a ha compact coral bed, containing large specimens of Madrep cinerascens: then succeeds the superior bed, abundantly charg with shells, both univalves and bivalves. Among these are

Ammonites,	19 species	Carditæ, .	4 species
Nautili, .	3	Lutrariæ, .	3
Belemnites,	3	Astartes, .	4
Trochi, .	12	Unios, .	2
Nerita, .	1	Myas, .	2
Cirrhi, .	2	Fistularia, .	1
Planorbis, .	1	Mytilus, .	1
Melaniæ, .	2	Modiolæ, .	2
Turbo, .	1	Donax, .	1
Rostellariæ,	3	Pinna, .	1
Turritellæ,	3	Terebratulæ,	11
Ampullariæ,	3	Ostreæ, .	6
Serpula, .	1	Pectines, .	4
Trigoniæ, .	4	Limæ, .	2
Arca ? .	1	Avicula, .	1
Cucullæa, .	1	Perna, .	1
Nucula ? .	1	Plagiostomata,	3

These beds present a considerable number of species belonging to the family of echini. They are enumerated by Conybeare in the *Outlines of the Geology of England and Wales.*

3. *Lias.* The lowest bed of all, upon which the whole oolitic formation rests, is called *lias limestone,* I do not know for what reason. The *lias,* taken as a whole, may rather be described as consisting of thick argillaceous deposits intermixed with limestone, than as an argillaceous limestone; the upper portion of these deposits forming about two-thirds of their total depth, consists of beds of a deep blue marl, containing only a few irregular and rubbly limestone beds. In the lower portion the limestone beds increase in frequency, and assume the peculiar aspect which characterizes the lias, presenting a series of thin stony beds, separated by thin argillaceous partings, so that quarries of this rock at a distance assume a striped and ribbonlike appearance. In the lower beds the argillaceous partings become very slight, or almost disappear. Beds of blue marl with irregular calcareous masses generally separate these strata from the red marl belonging to the *new red sandstone,* which lies immediately below. Sometimes as many as 40 alternating beds of clay, marl and stone, may be reckoned, constituting a thickness (in the neighbourhood of Bath) of about 282 feet. In the midland and north eastern counties the thickness is about twice as great.

The lias limestone has a dull earthy aspect and a large conchoidal fracture. In colour, it varies in different beds from light slate blue or smoke grey to white, the former varieties usually constituting the upper, the latter the lower portions of the formation. When purest, it contains about 90 per cent. of carbonate of lime, and ten per cent. of clay; the blue lias makes a strong lime, distinguished by its property of setting under water; the white lias takes a high polish, and may be employed for the purposes of lithography, but we must distinguish it from the stone generally used for that purpose, which is brought from the quarries of Solenhofen, and is a much more recent formation.

The slate clay with which the lias alternates, is grey, brown, or black, is frequently bituminous, and often divides into laminæ as thin as common pasteboard. In the lias no fewer than 36 species of fossil plants have been discovered. Of these, 12 species are cryptogamous plants; namely,

2 equisetums,
9 filices,
1 lycopodites.

23 species belong to cycadeæ, and 1 species is a zosterites.

It is in the lias beds that the bones of the two extinct species of lizard, the *ichthyosaurus* and *plesiosaurus*, occur.

Bones and palates of the turtle have been found in the lias beds. Several species of fish have been also met with, which have been referred to the genera *sparus* and *chætodon;* but probably they belong to fish unknown in a recent state; the radius of a species of *balista* is of common occurrence.

The leech-like palate *tritores* of some species of fish, and teeth in form resembling those of the shark, are occasionally found.

Several species of crab, and a species of *monoculus*, or *limulu* of Lamark, are also found.

The following are the shells enumerated by Conybeare:—

Ammonites 20 species.

The Ammonites having the siphuncle in an elevated ridge between two furrows, are characteristic of this formation. These are

Ammonites stellaris,		Tornatilla,	1
———— Walcotii,		Melania,	1
———— Brookii,		Modiola,	4
———— Bucklandi,		Unio,	2
———— Conybeari,		Terebratula,	3
Nautili, 3 species,		Spirifer or Pentamerus,	1
Scaphites equales,		Gryphæa,	2
Belemnites, many species,		Pecten,	
Helicina,	3 species	Plagiostoma,	2
Trochus,	3	Lima, &c.	1

The characteristic shells of this formation are the Ammonites Bucklandi, Gryphæa incurva and plagiostoma gigantea.

The lias formation stretches across from the coast of the German Ocean in Yorkshire to that of the channel in Dorsetshire. On the east coast it may be traced from the Peak alum works south of Whitby, nearly to the Teesmouth. Turning southward from the Tees it passes York on the east, and crosses the Humber a little eastwards of the junction of the Trent and Ouse, stretching onwards to the Woldhills, on the borders of Nottingham and Leicester, and the celebrated quarries of Barton-upon-Soar, whence it continues through the counties of Nottingham, Warwick, and Gloucester; its whole course along this extensive line, to a few miles south of Gloucester, is remarkably regular, presenting an average breadth of about 6 miles, bounded on the south-west by the oolites and on the north-west by the red marl, but beyond that point its course becomes much more intricate; for while its eastern limit still continues to occupy the oolitic range through Somersetshire to the coast in Dorset, its western limit becomes very irregular, feathering in and out among the coal fields which occur towards the estuary of the Severn and the upper part of the Bristol channel in Gloucestershire, Somersetshire, Monmouthshire and Glamorganshire, and attended by numerous outlying masses; these intricacies, however, have been minutely traced and explained by the English geologists.

The alum slate at Whitby constitutes a bed in the lias. Over this alum slate lies a bed of hard compact stone from six to twelve feet thick. The workmen call it *dogger*, a name by which they also designate the *septaria* or *cement-stone*, and the component parts of both appear to be nearly the same; the whole of the upper part of the alum slate resembles indurated clay when first worked, but by exposure to the atmosphere it suffers decomposition and crumbles into thin layers; the colour of the slate is bluish grey, it varies in hardness and abounds in pyrites. When a quantity of it is laid in a heap and moistened, it takes fire of itself and continues to burn till the whole combustible portion is consumed.

The coal beds which occur in the neighbourhood of Whitby lie over the lias formation, and consequently are situated in the undermost oolitic system. The Brora coal field on the east coast of Sutherland in the north of Scotland, is similarly situated. It forms part of the deposits which, on the south-east coast of Sutherlandshire, occupy a tract of about twenty miles in length, from the Ord of Caithness to Golspie. Its breadth does not exceed three miles; it is divided into the three valleys of Brora, Loth and Navidale, by the successive advance to the coast of portions of the adjoining mountain range, which bounds them on the west and north-west. The first of these valleys is flanked on the south-west by hills of red conglomerate, which pass inland on the north-east of loch Brora, and give place to an unstratified granite, which forms the remainder of the mountain boundary.

The highest beds at Brora consist of a white quartzose sandstone, partially overlaid by a fissile limestone, containing many fossils, the greater number of which have been identified with those of the calcareous grit, below the *coral rag*, showing clearly that the coal beds are situated lower down in the series than the coral rag, which constitutes the uppermost part of the middle oolitic system. The next bed consists of shale, with the fossils of the Oxford clay, which is the lowest stratum of the middle oolite, overlying a limestone resembling *cornbrash* and *forest marble*, which constitute the upper portion of the lowest oolitic system.

To these succeed sandstone and shale, containing belemnites and ammonites, through which the shaft of the present coal pit is sunk to the depth of near 80 yards below the level of the river Brora.

The principal bed of coal is three feet five inches in thickness, and the roof is a sandy calcareous mixture of fossil shells and a compressed assemblage of leaves and stems of plants, passing into the coal itself. The plant of which the Brora coal appears to have been formed, is identical with one of the most characteristic vegetables of the Yorkshire coast, but differs essentially from any of the plants found in the coal measures situated below the new red sandstone.

The base of the entire series is seen at low water near the north and south *sutors* of Cromarty, where the lias, with some of its characteristic fossils, may be seen resting on the sandstone of the red conglomerate.

There are two beds of coal at Brora, the highest of which crops out on the sea-shore. It began to be worked in 1598, and has been since frequently abandoned and again resumed. Mr. Williams, the well-known author of the *Mineral Kingdom*, took a lease of it in 1764, and worked it unsuccessfully till 1769, when he resigned his lease to Messrs. Robertson and Co., of Portsoy.

The second, or lowest bed which is worked at present, is three feet ten inches thick; but it has a pyrites band in the centre about eight inches thick. This was the origin of the bad character which the Brora coal acquired, and of its supposed liability to spontaneous combustion. It was pointed out and its bad effects obviated by Mr. Beaumont of Limekilns, in 1776, when he was employed to survey the country.

In 1810, Mr. Hughes, from Flintshire, was employed by the Marquis of Stafford to examine the field and open a new pit near Brora. In 1824, the coal raised annually was about 10,000 tons, of which about 6,000 were consumed on the spot in a salt work, which yielded about 300 bushels of salt weekly. The remaining 4,000 tons were consumed in the country.

On the north-west coast of Scotland several members of the oolitic series were recognised by Dr. Macculloch in the isles of Skye, Pabba, Scalpa, Mull, &c., and his observations have been confirmed and extended by Mr. Murchison.

In France, the great oolitic series appears in Normandy, occupying a considerable portion of the department of Calvados, and extending from the west bank of the mouth of the Seine, or a little west of that as far as Carenton, so that the cities of Caen and Bayeux are situated in it. The same formation constitutes the lower part of the range of Mount Jura. Hence the reason why on the continent the term *Jura limestone* is usually substituted for *oolite.*

It occurs also in great force in the north of Germany, though it would be rather hazardous to venture to assign English names to the German terms. The *Muschelkalk* is a formation in the upper part of the *new red sandstone,* which is wanting in Great Britain. Whether the *buntsandstein* of the north of Germany, with its equivalent, *Keuper,* in the south, belong to the new red sandstone or oolite is not so clear. The keuper occurs near Heidelberg in considerable quantity, and seems to lie under the lias;* and Brongniart considers it as constituting a formation immediately under the lias.

The uppermost keuper beds consist of fine-grained calcareous sandstone, the undermost of marl. Thin beds of gypsum are found in the marl. Beds of slate clay occur also in one place under the marl. The following fossil plants have been observed in the keuper:—

Equisetum arenaceum, the *calamites arenaceus major* of Jaeger.

Various leaves, &c., not yet made out.

The *Mergelkalk* of Boué, and the *quadersandstein* of Humboldt, which occupies a large tract of country on the banks of the Elbe above Dresden, and between Pirna, Schanden and Königstein; between Nuremberg and Weissenberg; at Staffelstein in Franconia; at Teufelsmauer at the foot of the Hartz; the valley of the Mozelle, and the neighbourhood of Luxemburg; in Lorrain at Vic; at Nalzen in the country of Foy, and at Navarreins at the foot of the Pyrenees—belong,

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* See Brown's Gæa Heidelbergensis, p. 145.

I think, to the oolitic series, though some refer them to the chalk.

In Britain, France and Germany, the oolite consists of very nearly the same beds; but in Poland the mineralogical structure seems to be altered. The undermost beds are more or less white and marly. On this rests *dolomite* generally of a dazzling whiteness, affording the forms so remarkable in rocks of this nature, and composing the picturesque country between Oldkusz and Cracow, and near Kromolow, Niegowomie, &c., rising to the height of 1,400 feet above the sea. The upper part of the Dolomite, from Oldkusz towards Zarki, and especially near Wladowice, contains pisiform iron ore. It there becomes mixed with a coarse sandstone. The upper portion of the group is formed of grey and oolitic limestones and calcareous conglomerate, and passes gradually into the lower beds of the green sand formation. The rocks of the oolitic group rest unconformably on the *coal measures* and *muschelkalk* of Poland. They have a general direction N.N.W. and S.S.E. From Weilun they plunge beneath the great plain of Poland, here and there appearing as islands above it. The organic remains establish the identity of this deposit with the oolitic series of other parts of Europe.*

There occurs, also, a series of equivalent deposits in the Alps, the Carpathians and in Italy, with little or no resemblance to the oolite of this country. But the characters, especially in the Alps, are so peculiar that the formations can only be identified by means of organic remains; and there occur such singular mixtures of these, that the determination of particular deposits is far from certain. Instead of marls, clays, sands, and light-coloured limestones, we have dark-coloured marbles, masses of crystalline dolomite, gypsum and slates approaching to talc and mica slates.

What renders the investigation of the Alps still more difficult, is the confusion into which the rocks have been thrown by the power which elevated them. Whole mountain masses have been thrown over, and the rocks really deposited the latest occur beneath the older strata. These dark-coloured rocks were referred by the Wernerians to the transition class, and we are indebted to Dr. Buckland for first pointing out their more recent origin. Since that time M. Elie de Beaumont has investigated these rocks in Savoy, Dauphiné, Pro-

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* Pusch, Journal de Géologie, t. ii.

vence and the maritime Alps. He showed that the beds described by Brochant in his Memoir on the Tarentaise, and which in many places contain masses of granular limestone and micaceous quartz rock, as well as large masses of gypsum, belong to the oolitic group.

In a notice on the geological position of the fossil plants and graphite found at the Col de Chardonnet (Hautes Alps), M. Elie de Beaumont observes, that as the traveller quits the Bourg d'Oisans (Piedmont) and approaches the continuous range of masses called *primary*, that extend from Mont Rosa towards the mountains on the west of Coni, he will perceive that the secondary rocks gradually lose their original character, though certain distinguishing marks may still be seen—thus resembling a half burnt piece of wood, in which the ligneous fibres may be traced far beyond the part which remains wood. The vegetables found by M. Elie de Beaumont in these situations were examined by M. Ad. Brongniart, and many were found by him to be the same as those which occur in the coal measures. The following are the chief of these plants:—

Calamites Suckowii,
———— Cistii,
Lepidodendron, 2 species,
Sigillaria,
Stigmaria,
Neuropteris gigantea,
———— tenuifolia,
———— flexuosa,
———— Soretii,
———— rotundifolia,
Odontopteris Brardii,
Odontopteris obtusa,
Pecopteris polymorpha,
———— pteroides,
———— arborescens,
———— platyrachis,
———— Beaumontii,
———— Plukenetii?
———— obtusa,
Asterophyllites equisetiformis,
Annularia brevifolia.

These vegetable remains are so far associated with *belemnites*, that the latter occur both above and below them; so that they must have existed both before and after the vegetable deposits. The same series of beds is continued to Digne and Sisteron, where they contain the characteristic fossils of the lias.

It would be impossible, without far exceeding the necessary limits of this work, to give a detailed account of all the Alpine rocks which are referrible to the oolitic group. The reader is referred to the various papers published on the subject by Studer, Boué, Sedgwick, Murchison, Lill von Lillienbach, Lusser, &c. We refer also, for an excellent abridgment of the present state of our knowledge of the oolite group, to De la Beche's *Manual of Geology*, p. 311.

CHAP. XI.

NEW RED SANDSTONE.

This formation lies under the oolite and over the coal measures, but in an unconformable position.' In England it begins at the river Tyne at Tynemouth, and extends in a southwesterly direction as far as Cheltenham, covering a considerable portion of the surface of the counties of Durham, York, Nottingham, Stafford, Warwick, Cheshire and Shropshire. The best description of it has been drawn up by Professor Sedgwick of Cambridge.

It consists, in this country, of two distinct subordinate formations; namely, the *new red sandstone*, which is uppermost, and the magnesian limestone, which is undermost. The *muschelkalkstein*, which in Germany exists in the upper part of this formation, has not yet been discovered in Great Britain. It occupies a great proportion of the north of Germany, namely, Hanover and Westphalia. In South Germany it extends from Hanau to Stuttgard.

In the new red sandstone formation a considerable number of petrifactions occur, both vegetable and animal; and, from the researches of Mr. Sedgwick, it appears that they bear a closer resemblance to those found in the coal measures than had been supposed.

The impressions of plants are chiefly observed in the sandstone beds. It is in the neighbourhood of Strasburg that these fossil remains have been chiefly met with. We are indebted to M. Voltz for the description of 20 species of fossil plants, found in that vicinity. Of these, 3 are impressions of equisetums, 6 of ferns, 5 of coniferous plants, 2 of liliaceous plants, and 3 are monocotyledonous, but not referrible to any known tribe. The vegetable remains at Lennel braes on the Tweed, about two miles east from Coldstream, which have been so ingeniously investigated by Mr. Witham, are usually referred to the coal measures, though both the coal measures and the new red sandstone occur at no great distance from them.

In Germany, the beds which correspond with our magnesian limestone, have received the name of *Zechstein*. The magnesian limestone does not abound in fossils; but several shells, all seemingly sea shells, have been found in that formation, especially in Hambleton hill, near Sunderland. It consists of a porous limestone, containing many casts of shells and corallines. The *producta* of Sowerby is conspicuous among these casts. We find also a species of *donax*, with hairlike spines, and smooth-shelled bivalves, from the size of a pea, to that of a cockle, resembling those of the genus *donax*. Casts of arcæ and anomiæ are also met with. Impressions of a reticulated marine production, resembling the genus *flustra;* also encrinites, and alcyonites; also casts of bivalves, resembling muscles, and small round bodies, the nature of which has not been made out.

The *red sandstone formation*, taken in its most comprehensive sense, consists of the following beds, beginning with the uppermost:—

1. Variegated marl,
2. Muschelkalk,
3. Red or variegated sandstone,
4. Zechstein, or magnesian limestone,
5. Red conglomerate, the *Todtliegende* of the German geologists.

1. The *variegated marls* are very conspicuous in the district of the Vosges, and have been minutely described by Elie de Beaumont. They may be seen likewise on the southern coast of England. In the Vosges, they commence beneath the *lias sandstone*, into which they gradually pass. The upper part of these marls has a green colour, and presents thin beds of black slate clay, and of quartzose sandstone, nearly without cement. This last passes gradually into the lias sandstone. In the environs of St. Leger-sur-Dheune, and at Autun, these deposits cannot be separated from the lias sandstone, constituting, in fact, only one deposit with it. This is the case also in the *arkose* of Burgundy. In the Vosges, the variegated marls are usually marked with different colours; the principal of which are, wine red, and greenish or bluish grey. They break into fragments, which have nothing of a slaty structure. In the central portions of them, there are beds of black slaty clay, bluish-grey sandstone, and greyish or yellowish magnesian limestone. The sandstone and clay contains vegetable impressions, and even coal. Masses of rock salt occur in the lower part of these marls; and masses of gypsum are found in the upper and lower portions, but principally in the latter.

These variegated marls, according to M. Dufresnoy, crown the red sandstone rocks in the south of France. Mr. De la Beche is of opinion, that the upper part of the red sandstone deposit in England corresponds in its mineralogical character with the variegated marl of the Vosges. There is no apparent transition of the lias into the red sandstone series in England. At the old Passage, near Bristol, there occurs a conglomerate, composed of pieces of limestone, bones, teeth, and other remains of saurian animals and fish, with *coprolites.** This would seem to mark a period when comminuted deposits ceased, and currents of water, sufficient to transport pebbles, were in action. Between Lyme Regis and Sidmouth, on the south coast of England, the upper part of the red sandstone series resembles very closely the variegated marls of the Vosges. The following table exhibits a list of the fossil vegetables found in this bed, as collected by M. De la Beche.*

Equisetum Meriani,
——— columnare,
Pecopterus Meriani,
Tæniopteris vittata,
Pterophyllum longifolium,
Pterophyllum Meriani,
——— Jægeri,
Calamites arenaceus?
Filices Stuttgardiensus,
——— lanceolatus.

The following amphibious animals have also been met with in the variegated marls:—

Phytosaurus cylindricodon,
——— cubicoden,
Ichthyosaurus,
Plesiosaurus.

Also,

Posidonia Keuperina,
Saxicava Blainvillii.
Ophiura,

In Poland, between the oolite and muschelkalk, there is an extensive deposit of sandstone, usually termed *white sandstone*, from its colour. It is divisible into two portions, the upper being formed of white sandstone, and the lower of alternations of fine white marly sandstone, slaty sandstone, shale, and other slaty and dark-coloured rocks; the whole enclosing beds of coal, from 3 to 25 inches thick. The white sandstone of the upper part alternates with thick beds of grey-blue marls, partly red, and more rarely variegated. Beds of limestone are also found in it. But the most valuable product is iron ore, which furnishes the largest amount of iron of any rock in Poland, twenty-seven furnaces affording annually about 560,000 quintals of metal. Fossils are rare in this deposit, except vegetable

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* This name has been given to the supposed fossil fæces of quadrupeds, found in caverns, &c.

† Manual, p. 391.

remains. It seems to unite the characters of the lias sandstones and variegated marls.*

2. *Muschelkalk.* This consists of a limestone, varying in its texture; but most commonly grey and compact. It is occasionally dolomitic, and passes into marls above and below. When very compact, with numerous remains of the *Encrinites moniliformis*, (a very characteristic fossil,) it has much the appearance of the mountain limestone of England. It is sometimes so hard, that it is employed as marble. For example, at Epinal, in the Vosges. In some situations, organic remains are very abundant in it, while in others they are rare. This formation does not occur in England, nor in the north of France. But it is found in the south and east of France, and in Germany, where it is interposed between the variegated marls, and the red or variegated sandstone. According to Pusch, it occurs in Poland, and is described as being grey and yellow. The following table exhibits the organic remains in this formation:—†

Fish teeth,
Plesiosaurus,
Ichthyosaurus,
Another saurus, genus not determined.
Palinurus Sueurii,
Nautilus bidorsatus,
——— nodosus,
Ammonites nodosus,
———— bipartitus,
———— Henslowi?
———— latus,
———— subnodosus,
Buccinum obsoletum,
Turritella terebralis,
Dentalites torquatus,
——— lævis,
Terebratula perovalis,
———— sufflata,
———— vulgaris,
———— orbiculata,
Trigonia vulgaris,

Trigonia pes-anseris,
Mytilus eduliformis,
Avicula socialis,
Myacites musculoides,
——— intermedius,
——— elongatus,
——— ventricosus,
Pecten reticulatus,
Ostrea sphondyloides,
Cardium striatum,
Plagiostoma lineatum,
———— rigidum,
———— lævigatum,
———— punctatum,
Serpula valvata,
——— colubrina,
Encrinites moniliformis,
——— epithonius,
Ophiura prisca,
——— loricata,
Asterias obtusa,
Astrea pediculata.

The only vegetable impression is that of the neuropteris Gailliordoti.

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* Pusch, Jour. de Géologie, tom. ii.

† From De la Beche's Manual, p. 393.

3. *Red or variegated sandstone.* This stone is most commonly red, but is found also white, blue, and green. It is principally siliceous and argillaceous, sometimes containing mica, masses of gypsum, and rock salt. In the neighbourhood of Glasgow, it is characterized by numerous circular spots of a white colour, seemingly composed of indurated clay. In the Vosges, the upper part of the variegated sandstone presents thin beds of marly limestone and dolomite, which gradually becomes more abundant, so that finally they constitute the lower part of the muschelkalk. An oolitic and calcareo-magnesian rock is found in it, in some parts of Germany.

What is called *gres de Vosges*, is considered by Voltz as belonging to the variegated sandstone; while Elie de Beaumont thinks it belongs to a lower part of the new red sandstone series. It is composed of amorphous grains of quartz, commonly covered with a thin coating of peroxide of iron, among which are discovered fragments of felspar crystals. It is often marked by cross and diagonal laminæ, so common in sandstone rocks. It contains quartz pebbles, sometimes in such abundance, as to represent a conglomerate with an arenaceous cement.

The variegated sandstone affords frequently a good building stone, and when nearly free from colour, it has a handsome appearance. There is a quarry of it some miles west from Dundee, upon the Firth of Tay, which has a brownish-white colour, and which constitutes a very durable stone. It is of it that the numerous new streets, at present rising in Dundee, are built. Quarries of it also exist behind Helensburgh, a village opposite to Greenock, on the Firth of Clyde, the stones from which are employed in building that village. The ground rises behind Helensburgh for about a mile, and reaches an elevation of at least 200 feet. It then slopes gently towards Lochlomond, distant about 8 miles. The surface of this elevated valley is pretty smooth, and, where it is not covered with moss, consists of a white arenaceous clay, quite filled with water-worn pebbles of all sizes, from a grain of sand to several tons. By far the greater number of these fragments are clay slate, of which the neighbouring mountains are composed; but pebbles of quartz, granite, greenstone, and even of sandstone, are also frequently observed. Below this alluvial soil, the whole country is composed of beds of sandstone, of various colours, sometimes white, sometimes yellow, and often red, or brownish red. The sandstone consists chiefly of fragments of either white or coloured. Sometimes the quartz grains ırge as to constitute a conglomerate. The beds dip the south-east. The sandstone beds vary from 1 foot t thick, and are separated from each other by thin beds : blue-coloured slate clay. The beds on the south side 'irth, at Greenock, and along the sea-shore, as far as e, are composed also of new red sandstone: doubtless hind Helensburgh are a continuation of the Renfrewds.*

red sandstone of the Vosges contains, according to M. he following shells:—

ıtula,
;oma lineatum,
—— striatum,
a,

Turritella Schoteri,
Mytilus eduliformis,
Myacites elongatus,
——— musculoides.

ıd. Brongniart enumerates the following fossil plants ı this formation at Sulz-les-Bains:—

es arenarius,
— Mougeotii,
— remotus,
›teris Mougeotii,
teris Voltzii,
—— elegans,
›teris Myriophyllum,
—— palmetta,
ı scolopendroides,
brevifolia,

Voltzia elegans,
——— rigida,
——— acutifolia,
——— heterophylla,
Convallarites erecta,
————— nutans,
Paleoxyris regularis,
Echinostachys oblongus,
Æthophyllum stipulare.

chstein. This name was applied by Humboldt to ish a limestone series of a very variable character, to 'arious names were given, the term *zechstein* being to only one of the varieties. The various beds of it stinguished by the German miners, by the names of *friable marl)*, *stinkstein (fetid limestone)*, *rauchwacke*, ı, and *kupferschiefer* (copper slate). This lowest being worked for the copper which it contains in ld, Thuringia, Franconia, and the Hartz. The mean

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sandstone lies immediately over the primary clay slate of the 'hood. It is therefore usually considered as old red sandstone; e been unable to trace any interposing beds between them and the which, near Glasgow, evidently lies over the coal; and, therefore, onsidered as *new red sandstone.* Fine sections of it may be seen rders of the Gare Loch, between the village of Helensburgh and thickness of the copper slate in these countries is about a foot. The zechstein varies from 20 to 30 yards thick; the rauchwacke, when pure and compact, one yard thick, when cellular, sometimes fifteen or sixteen yards thick. The stinkstein varies in thickness from one to thirty yards, and that of the asche is very variable.

The magnesian limestone of the north of England, which is the equivalent of the German zechstein, consists, according to Professor Sedgwick, of the following subordinate beds:—

1. Marl slate and compact limestone, or compact and shelly limestone and variegated marls.
2. Yellow magnesian limestone.
3. Red marl and gypsum.
4. Thin bedded limestone.

No. 1, he considers as the equivalent for the kupferschiefer and zechstein, and Nos. 2, 3, and 4, to the rauchwacke, asche, and stinkstein, of Thuringia.

For the organic remains in zechstein and copper slate, we refer the reader to the catalogue given by De la Beche.[*]

5. *Red conglomerate.* The name *todtliegende* is given by the Germans to a series of red conglomerates and sandstones, which occur between the zechstein and the coal measures. In Thuringia, the term is applied to those beds that lie immediately under the copper slate. It is for the most part a conglomerate formed from the partial destruction of those rocks on which it rests, the fragments being sometimes angular as well as rolled, and of considerable size.

In England, the magnesian limestone begins at Tynemouth, and extends with little or no interval, as far as Nottingham, or about 147 miles. During this extent, it assumes a great variety of appearances, and perhaps even varies in its composition. In the neighbourhood of Sunderland it constitutes low hills, which are quarried in several places, and being converted into lime, is carried in great quantities to the north-east coast of Scotland, where it is used as a manure. It is a moderately compact limestone of a yellow colour, and is composed of

1 atom carbonate of lime, . .	6·25 or	54·35
1 atom carbonate of magnesia, .	5·25 or	45·65
		100·00

The surface of this magnesian limestone is in many places

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[*] Manual, p. 398.

covered with a poor herbage, uncommon to limestone. This has been ascribed to the magnesia contained in it, which is known to be unfavourable to vegetation.

At Sunderland, the thickness of the magnesian limestone in some places, is at least 600 feet. To the south of Nottingham it may be seen, not far from the slates of Charnwood forest, on the north and north-east border of the Ashby-de-la-Zouch coalfield. Patches of it occur near Bristol: indeed the rock on which Lord de Clifford's house (west of Clifton) stands, is a magnesian limestone.

The magnesian limestone lies immediately over the conglomerate or sandstone bed, which covers the coal measures in an unconformable position. This may be distinctly seen at Cullercoats in Northumberland, near Tynemouth, at the western extremity of its northern boundary. It overlies the 90 fathom dyke, which appears between the strata of coal in nearly a vertical position. This dyke passes through the coal measures, but not the magnesian limestone. Thus, it is evident that the magnesian limestone was deposited not only after the coal measures, but after the dyke had penetrated the coal field.

The coal measures near Whitehaven, on the west coast, may also be seen passing under the magnesian limestone of that district. According to Mr. Farey, the coal beds in Derbyshire extend under the magnesian limestone, and have been wrought under it at Bilborough and Nuthal, a few miles north-west of Nottingham. Coal has never been got at by penetrating through the magnesian limestone; but it has been often worked under that bed, and it is an ascertained fact, (though no good reason can be assigned for it) that the coal covered by the magnesian limestone is of inferior quality.

The new red sandstone which lies over the magnesian limestone, appears on the sea-shore a little to the north of the Tees, in the county of Durham. It passes through the whole county of York, and is broadest at the city of York, which is situated in that formation. It becomes somewhat narrower in Nottinghamshire. In Leicestershire it is very broad, including most part of the counties of Warwick, Stafford, Shropshire, and Cheshire. In the north of England, the new red sandstone covers the valley of Carlisle, and runs south-east into Westmoreland, and north-west into Dumfries-shire. It appears again in Berwickshire on the north banks of the Tweed. On the northern side of that county, it is interrupted by the great transition chain which runs from St. Abb's Head to Loch Ryan; but it appears again in East Lothian, and continues till the coal measures terminate a little to the east of Tranent and Salton.*

The greater part of the lowland portion of Perthshire, namely Strathallan, Strathearn, Carse of Gowry, and part of Strathmore, consist of red sandstone beds, which have nearly a horizontal position, and in this respect form a remarkable contrast to the position of the greywacke beds, on the east side of the Grampians. On this account, I have little doubt that the whole of these red, or rather variegated, sandstones, belong in reality to the new red series, though this is not the general opinion of mineralogists. On the east side of Scotland, these red sandstone beds proceed without interruption as far as Stonehaven in Kincardineshire, where the primary rocks make their appearance a little beyond the river. There are strong reasons for concluding, that the greatest part of the County of Caithness, and the whole of the Orkneys, belong to the same formation. That the sandstone round Inverness belongs to the same formation is rendered probable by the nodules of sulphate of strontian which occur in it.

The sandstone on the coast of Ayrshire, indeed, from Greenock to Saltcoats, along the shore, and likewise in the Cumbraes, and at least, a portion of that in the Islands of Bute and Arran, is undoubtedly a part of the same formation. In short, at least as great a proportion of Scotland as of England consists of this great formation. Thin beds of magnesian limestone may be occasionally seen on the banks of the Tweed, and also of gypsum; but the beds of these rocks, which are so thick in England and Germany, are entirely wanting in Scotland.

The fossil plants hitherto observed in the new red sandstone formation, amount to 21 species. Of these 12 are cryptogamous; namely,

4 calamites,	8 filices.

Eight species are flowering plants; namely,

5 coniferæ,	1 echinostachys,
1 æthophyllum,	1 paleæxyris.

One species, a juglans, belongs to a recent plant.

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* The sandstone of Berwickshire is sometimes referred to the *old red sandstone* formation. But at Eccles quarry, beds of magnesian limestone may be seen passing under it; and at Lennel braes, on the Tweed, it seems to overlie the coal beds.

CHAP. XII.

COAL MEASURES.

IMMEDIATELY under the new red sandstone formation lie the *coal measures*, fortunately so abundant in Great Britain, as they constitute the great source of our industry and wealth. All the manufacturing districts in Great Britain, with a few exceptions, which admit of an easy explanation, are situated in the immediate vicinity of coal. Bristol, Coventry, Birmingham, Swansea, Wolverhampton, the potteries, Nottingham, Sheffield, Manchester, Halifax, Leeds, Huddersfield, Newcastle, Glasgow, are all situated in coal districts.

Coal fields occur usually in valleys or troughs, of greater or smaller magnitude, and they extend to a considerable distance all round, without any great alteration in the dip or position of the various beds, except where they have been altered by the interposition of *dykes*, or by *slips*, as they are called, that is to say, by the elevation of one portion of a coal field and the depression of another. A remarkable example of this occurs in the Newcastle coal field. A little to the north of Newcastle, there is a narrow dyke which runs west, and consists of nothing but clay. It must have been formed by the coal beds being separated at that particular line. Now, the remarkable circumstance is, that the same beds occur on both sides of the dyke, but the corresponding beds are 70 fathoms, or 420 feet higher upon one side of the dyke than upon the other. It is clear that the beds must have once been on a level. By some unknown convulsion of nature, the whole strata on one side, constituting a surface of many square miles, must have been depressed or elevated 420 feet, while those on the other side remained unaltered in their position.

No connexion can be traced between the different coal fields. On that account, Werner gave to the coal measures the name of the *independent coal formation*. Yet as similar strata occur in all coal fields, there can be no doubt that they were all deposited under similar circumstances, and at the same period of time.

A coal field consists of a great number of beds placed very regularly above one another, varying much in their thickness and in their constitution and generally dipping towards a particular line, which constitutes the lowest part of the basin in which the coal metals are situated.

The rocks which constitute these coal measures, are *sandstone*, *slate clay*, and *coal*. Sometimes *mountain limestone* is intermixed with these beds.* This is the case in the Newcastle beds, the Edinburgh beds, and the Glasgow beds. It is said also, that occasionally beds of greenstone and basalt occur in them. It is probable that such beds are only of partial extent, and that they are connected with the trap dykes which constitute so prominent a feature in the coal districts. The slate clay is sometimes mixed with so much coal or bituminous matter, as to give it a black colour, and to make it combustible. It is then distinguished by the name of *shale*, or *bituminous shale*. Beds of *clay ironstone*, or *carbonate of iron*, occur also in the coal measures, especially in the neighbourhood of Swansea, Wolverhampton, and Glasgow. But it is remarkable that they are wanting in the Newcastle coal beds, and in most of those which occur in France.† It is from this ore that the prodigious quantity of iron smelted annually in Great Britain (above 600,000 tons) is obtained. The fortunate circumstance of its occurring along with coal greatly reduces the expense of the manufacture of iron in this country. While in France, where this connexion does not exist, the necessary expense of the manufacture is unavoidably much greater.

The coal measures are much intersected by dykes of greenstone and basalt running through them in various directions. In general the coal in the immediate neighbourhood of these dykes is injured in its quality. But what is more remarkable, the beds of the coal measures upon one side of these dykes, are almost always higher than on the other side. Hence these dykes are often called *troubles*, on account of the great trouble which they give the miners to discover the bed of coal upon the other side of a dyke which they have dug out, on the side at which they were working as far as the dyke itself.

The sandstone which occurs in the coal beds varies much in its colour and the size of its grains. The grains are chiefly of quartz, obviously water-worn, and interspersed with particles of mica. Sometimes nodules of slate clay, or of carbonate of iron occur in this sandstone, and it is seldom quite free

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* Hence called *carboniferous limestone* by the English geologists.

† In Burgundy, however, the ironstone and coal occur in contiguous situations.

from fossil wood converted into coal. About Newcastle it is too soft and friable to answer as a building stone. Near Edinburgh, and in Fife, it is nearly white, small-grained, and very durable. It answers admirably as a building stone. Near Glasgow, the upper beds have usually more or less of a red colour, and the grains are coarser than those of the Edinburgh stone. But the lower beds are as white as the Edinburgh stone, and almost as fine-grained. It constitutes a building stone, hardly, if at all, inferior to the Edinburgh stone as a building material, while the quantity all round the city is prodigious. Hence the new built Glasgow streets are hardly, if at all, inferior to the finest streets in the new town of Edinburgh.

The sandstone is composed of a number of beds lying above each other, like the leaves of a book. Some very thin and some many feet thick. Hence it is easily cut into blocks, or slabs of almost any size, by means of wedges driven into it. The pillars in the front of the college of Edinburgh, are about 28 feet long, and composed each of a single stone. This sandstone is a very lasting building stone. Melrose abbey, which is built of it, was finished in the year 1142, or almost 700 years ago; yet the cornices of the windows are as sharp and as perfect as if they had been carved only a few years ago. The cathedral of Glasgow is about the same age, and yet the stone work of it is still perfectly fresh.

In this sandstone casts of trees are very common. Sometimes these casts are lying in a horizontal position; but in general they are perpendicular, as if the trees had been growing at the time when they were enveloped in the sandstone. I have never been able to observe the branches or upper part of these trees, but only the lower part of the trunk and the roots. These casts consist of the very same sandstone with which they are environed. The trees are recognised by the bark which still surrounds the cast, having been converted into coal. Some conception of the origin of these casts may be formed, by supposing that the trees, of which these casts remain, had ceased to vegetate, had lost their tops and the upper part of their trunk, and that all the wood of the lower part had wasted away, leaving only the hollow bark. This bark would be naturally filled with the sand at the time that it was deposited, and being surrounded with sand would be retained in its original position. This sand was afterwards consolidated into stone under a great pressure, which will account for the conversion of the bark into coal.

These casts of trees are very common round Glasgow. About fifteen years ago there was a very perfect one in the quarry situated on the north side of Sauchiehall street. About 3 feet of the lower part of the trunk were uncovered. This portion was 40 feet below the upper surface of the quarry. The trunk was about 26 inches in diameter, not quite round, but oval, the north and south diameter being somewhat longer than the east and west one. This oval shape is not uncommon in trees at present vegetating in this country. It is owing to the influence of the sun occasioning a greater growth in the south side of the tree than the east and west sides. Four long roots were seen issuing from the trunk and dipping into the earth, pretty much as the roots of our beech trees may be observed to do at present.

About ten years ago an avenue of such fossil trees was uncovered at once, in a quarry situated a little to the west of the aqueduct bridge over the Kelvin, about three miles from Glasgow. The lower portion of four trees was visible, situated in a straight line, and at equal distances from each other. Some years ago, a large stem of a similar tree was found in Craig Leith quarry, near Edinburgh, in a sloping direction.* Such trees are common likewise in the Newcastle coal beds, and doubtless in many other situations. It was supposed that these trees were casts of monocotyledonous plants, but Mr. Witham, by polishing very thin slices, has shown that the Craig Leith tree, and likewise the casts found at Lennel braes to the east of Coldstream on the Tweed, belong to dicotyledonous plants. Indeed he has proved that all the lepidodendrons, so common in the coal beds, are *pines.*

The sandstone of the coal beds always, or almost always, contains plates of mica, sometimes in great abundance, sometimes scanty. When the grains of which they are composed are large, they are called *grits.* A variety of coal sandstone used for mill-stones, and situated in the lower part of the coal measures, is known in the north of England by the name of *millstone grit.* This sandstone is also used for whetstones, grindstones, &c. Coal sandstone is distinguished in England

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* A figure of this remarkable fossil in the position in which it was found, together with its dimensions, is given by Mr. Witham, in his late work on Fossil Vegetables, plate V.

by a variety of names. *Plate*, *post*, *pennant*, are some of the most common of these.

The *slate clay* varies a good deal in its appearance. Often it is a brown coloured soft clay, consisting of very thin slaty beds, lying above one another. Very often it contains a great deal of mica in small scales. Grains of sand are seldom wanting. Not unfrequently slate clay passes into sandstone, and during this passage it puts on a great variety of appearances. These varieties are distinguished by the names of *indurated slate clay*, and *clay sandstone*. In Northumberland and Durham, slate clay is called *hazel* by the miners, obviously from its colour, which in that country approaches to that of the bark of the hazel.

The beds of coal vary in thickness from that of a leaf of writing paper to 30, or even 80 feet.

These beds alternate with each other a great number of times in the coal basins. In the Northumberland coal field there are 240 beds, which have been cut through, constituting a thickness of 4035 feet. Of these, 30 are beds of coal, 62 are sandstone beds, varying much in their appearance. The lowest sandstone bed is 228 feet thick. There are 20 beds of mountain limestone. The remaining 128 beds are chiefly of slate clay.*

The Edinburgh coal beds have been completely cut through. There are 337 beds consisting of sandstone, limestone, coal, slate clay, and shale. There are 80 beds of coal, but most of them are very thin. The beds of limestone amount to eight.

The Bristol coal field is 4440 feet thick. It contains 31 beds of coal, mostly very thin; but beds not exceeding three feet in thickness, are in that district worked with profit.

The coal beds contain a great number of vegetable impressions, a much greater number indeed than all the other formations put together. The species known and described amount to 260. Of these, 12 are coniferæ, 4 palmæ, 2 equisetums, 3 calamites, 107 filices, 12 lycopodites. Many of these, as has been already observed, are the casts of trees, or at least of plants, whose trunks emulated trees in size. These casts occur chiefly in the sandstone beds. Trunks or stems, usually flattened, as if they had been subjected to violent pressure,

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* See Westgarth Forster's Section of the Strata from Newcastle to Crossfell, p. 155.

occur also in the slate clay or shale. In the coal itself, for the most part, no vegetable impressions can be traced, though occasionally portions of coal occur, having exactly the structure and properties of wood charcoal. It is the universal opinion, that coal is nothing more than an accumulation of vegetable matter, which probably has been altered and converted into coal by the action of heat under a very great pressure. In the slate clay and shale, the impressions of leaves of various kinds are met with.

Not a single vegetable impression in the coal beds has been identified with any plant at present growing on the earth. They all probably belong to a warmer climate than ours, and they seem to have reached a size much greater than that o the same tribes of plants at present vegetating on the earth.*

We are indebted to M. Ad. Brongniart for the completes account of fossil vegetables which has yet appeared. Hi work, when finished, will contain figures of all the species o fossil plants hitherto met with. We shall borrow from hi Prodromus a sketch of the fossil plants belonging to the coa beds.

The vegetable kingdom has been divided by botanists int six grand classes; namely, *agamia*, *cryptogamia cellulos* *cryptogamia vasculosa*, *phanerogamia gymnospermia*, *phaner gamia angiospermia monocotyledonosa*, *phanerogamia angi spermia dicotyledonosa*.

The *agamia*, so called because they exhibit no traces flowers or seeds, comprehend the *algæ*, or sea weeds, t *fungi*, or mushroom tribe, and the *lichens*, or plants whi vegetate on stones or on the bark of trees.

The *cryptogamia cellulosa* comprehend the *mosses* a *Hepaticæ*. They have no vessels, but they have distin leaves. The organs of production are evident, but the par are so small, that the uses of the different organs have n been made out in a satisfactory manner.

The *cryptogamia vasculosa*, consist of the *equisetums*, t

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* From the observations of Mr. Hutton, made in the same way as M Witham's, by cutting thin slices of coal and examining the polished fa with a glass, it appears that the structure of coal is organized. Caki coal, splint coal, and cherry coal, besides a *reticulated* structure, exhib cells filled with a straw-coloured volatile matter, apparently bituminou These cells vary with the coal. In caking coal they are comparativel few and much elongated. The cherry coal contains two kinds of cells, t one similar to those in caking coal, the other smaller. In cannel coal, t first kind of cell is usually wanting, but the second kind is in abundance.

ferns, the *lycopodiaciæ*, the *marsilliaceæ*, and the *characeæ*. These plants have distinct vessels, and their leaves, in general, are large, and very much developed. The stems, when they are arborescent, have considerable analogy to those of the monocotyledonous shrubs and trees. Brongniart is of opinion, that most of the casts of the trunks which occur in the coal sandstone, belongs to this class of vegetables. But the late discoveries of Witham have thrown considerable doubts about the accuracy of this conclusion. There are reasons for believing that the equisetums, filices, &c. which are found in the coal measures, reached a much greater size than their representatives of the present time, even in the torrid zone. This cannot be explained without admitting, that the heat and moisture of the climate was at that time more favourable to vegetation than even the torrid zone is at the present day.

The fourth class, the *phanerogamia gymnospermia*, consists of two very remarkable families of plants, the *cycadeæ* and the *confervæ*. They are well distinguished from all other plants, by the structure of their organs of production. The seeds being destitute of capsules, receive directly the action of the fecundating substance. They are distinguished also by the organization of their stems, very different in several respects from those of true dicotyledonous plants. I am not aware that any remains of plants, belonging to this class, occur in the coal beds.

The 5th and 6th classes, consisting of monocotyledonous, and dicotyledonous plants, are similar to those which exist at present. Very few vegetable remains of the coal beds belong to these classes, unless we are to except the casts of trees, which Mr. Witham has shown to belong to the class of dicotyledonous plants. There are three species of fossil plants in the coal beds which have been referred to the *palmæ* or *palms*, a well-known tribe of monocotyledonous plants; and one species referred to the *cannæ*, also a tribe of monocotyledonous plants.

The number of species of plants, found in the coal beds, or those immediately below them, amounts to 240; of these, 4 belong to the class of agamia; 220 to the cryptogamia vasculosa; and 16 to the phanerogamia gymnospermia.

The names of the families, to which these plants have been referred are

Equisetum,	*Filices*,
	Calamites,

Sphenopteris, 21 species,
Cyclopteris,
Neuropteris, 11 species,
Pecopteris, 41 species,
Lonchopteris,
Odontopteris, 5 species,
Schizopteris,
Sigillaria, 41 species,
Marsilliaceæ,
Sphenophyllum, 7 species,
Lycopodiaceæ,
Lycopodites, 10 species,
Selaginites, 2 species,
Lepidodendron, 34 species,
Cardiocarpon,
Stigmaria,
Palmæ,
Flabellaria,
Nœggerathia,
Cannæ,
Cannophyllites.

For an account of all these families, with figures of each species, we refer the reader to Brongniart's work. A bare list, which is all that we could give here, would be of little use.

A great number of fossil shells, chiefly sea-water shells, has also been found in the coal measures. For a list of these, together with the localities of each, we refer the reader to De la Beche's *Manual of Geology*, p. 419.

Some fossil fish palates have been also met with near Leeds; and also the remains of fish, which, however, have not yet been referred even to a genus.

The mountain limestone, which alternates with the coal beds, contains also many fossil zoophites and shells. For a catalogue of these, we refer to De la Beche, p. 421.

The northernmost of the British coal fields occupies a considerable portion of the great central valley of Scotland; being cut off on the north by the Ochil hills, and the river Eden, in Fife; and on the south by the transition chain of mountains, running from St. Abb's Head to Loch Ryan, in Galloway. It begins at the south bank of the Eden, where it flows into the sea about 4 miles north from St. Andrew's, in Fifeshire. Its northern boundary for some way is the Eden; then the Ochil hills, till nearly as far west as Alloa. It then crosses the Forth, passes a little to the north of Bannockburn; and proceeding south-west, its boundary is the Campsie hills. About 8 miles west from Glasgow, it crosses the Clyde, and goes, in a south-westerly direction, to the north of Irvine.

On the south side, the coal field begins a little to the east of Tranent and Pitcaitland, in East Lothian. It is bounded on the south by the Lammermuirs and Pentlands. It is broadest of all in Lanarkshire, and gradually contracts as it gets to the west sea, and appears to terminate not far from Girvan, in the south of Ayrshire. There are a few offsets from this great field, constituting small coal tracts in Dumfries-shire. But they are insignificant.

The Mid Lothian portion of this coal field was surveyed, at the expense of the Duke of Buccleugh, by the late Mr. Farey; but the details of the survey have never been given to the public. The field constitutes a lengthened basin, dipping to the north. Hence the lowest beds crop out against the sides of the Pentlands. The uppermost bed may be seen at Musselburgh. These beds may be divided into three series: 1. The coal measures, properly so called, which consist of numerous beds of coal, alternating with beds of slate clay, shale, and sandstone. 2. Under this series lies a set of beds, composed of alternate strata of shale and sandstone, mixed with beds of limestone. The coal beds in it are few and unimportant. 3. In the third or lowest series, the mountain limestone predominates. The coal beds are reduced to slight traces, which have never been worked. The lowest bed of all is a red-coloured sandstone.

There are 337 beds in the Mid Lothian coal field; of these, 84 are beds of coal; but the greater number of them too thin to be worked. There are eight beds of mountain limestone. Altogether these coal beds constitute a thickness of about 5000 feet.

A table of the coal strata of Loanhead, which repose upon a limestone containing marine remains, and constituting a thickness of 2336 feet, is given by Dr. Hibbert, in the *Edinburgh Transactions*, vol. 13, page 250. Among these strata there are 26 beds of coal, constituting together a thickness of 94 feet. Between the limestone constituting the base of the Loanhead strata, occurs a considerable thickness, (not less than 2000 feet,) consisting of strata of shale, sandstone, thin seams of coal and of ironstone, the whole of which rests upon a bed of limestone, 27 feet thick.

This limestone crops out at Burdiehouse, about 4 miles south-east from Edinburgh, where it has been quarried for many years. Dr. Hibbert was the first person who examined this limestone; and he has published a most interesting account of it in the *Philosophical Transactions of the Royal Society of Edinburgh*.

It has a bluish-grey or blackish-grey colour, from the bituminous or vegetable matter which is abundantly diffused through it. In its composition, it very rarely shows any

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[*] Vol. 13, p. 169.

crystalline texture, such as is observable in the mountain limestone of neighbouring quarries. It has a dull earthy aspect, and yet is as hard as ordinary limestone. When fractured, it sometimes breaks into a slaty form, particularly when it is alternated with thin striæ of vegetable or bituminous matter. When these are absent, its fracture is conchoidal. In the quarry, it appears in regularly inclined strata, each about 4½ feet thick, and dipping towards the south-east, at angles of from 23° to 25°, while its seams of stratification are so regular as to afford, during the process of quarrying, a continuous surface of almost unlimited extent.

Dr. Hibbert has shown that this limestone is a fresh water formation, containing abundance of the same vegetable impressions that occur in the coal beds. The most common of the fossil plants in it is the sphenopteris affinis, figured by Lindley and Hutton, in their *Fossil Flora of Great Britain*, plate 45. This fern seems to be confined to the lowest part of the coal formation. It is the first plant which occurs above the transition slate in Berwickshire. In a similar position it was observed by Dr. Hibbert in Linlithgowshire and Ayrshire. The Burdiehouse limestone contains also impressions of sphenopteris bifida, sphenopteris linearis, and several other ferns. There occur also many Lycopodiaceæ; for example, the Lepidodendron selaginoides, L. obovatum, L. Steinbergii, Lepidophyllum intermedium, Cyperites bicarinata, Lepidostrobus variabilis, Cardiocarpon acutum.

This limestone contains a prodigious number of Entomostraca, ranging in size from $\frac{1}{12}$ to $\frac{1}{60}$th of an inch. The most remarkable of these is a cypris, to which Dr. Hibbert has given the specific name of *Scoto-Bordigalensis*, from the situation of the limestone.* To another of these minute creatures Dr. Hibbert gives the generic name of daphnoidia. Others resemble the planorbis or spirorbis, but probably constitute new genera.

But the most remarkable circumstance connected with the Burdiehouse limestone is the remains of fossil fish, which it contains in abundance. Dr. Hibbert gives a particular description, together with drawings, of the palæoniscus Robisoni, a new species determined by M. Agassiz, during his visit to Edinburgh, in the autumn of 1834. Another fossil fish found in the same place has been called, by Agassiz, *Eurynotus crenatus*.

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* Burdiehouse is a corruption of Bourdeaux house, so called because it was, in the time of Queen Mary, inhabited by her French attendants.

constitutes a new genus, belonging to his family of Lepi- ides. Another fish is a species of Amblyteras.

But the most extraordinary fossil remains are those of a fish an immense size to which M. Agassiz has given the name *Megalychthis.* It is referrible to the Lepidosteus spatula, fish which at present inhabits certain fresh-water lakes in uth America. This fish possesses considerable resemblance the crocodile of the Ganges. M. Agassiz was permitted dissect a specimen of this fish preserved in spirits in the ritish Museum; he found it possessed of lungs, and to have any close analogies with saurian animals. It would appear om this that in those remote periods of the world when the urdiehouse limestone was deposited, the fish were different their organization from those which at present exist; being le, from the lungs with which they were supplied, to live ther in water or on dry land. This provision of nature was ubtless intended to enable the fish to continue to exist, ough subjected to the rapid alternations of dry land and ater, which apparently took place at that remote period.

The megalichthys constitutes a new genus of fish, the spe- fic name of which, Hibberti, M. Agassiz, with great pro- iety, took from the eminent geologist to whose praiseworthy d indefatigable exertions we are indebted for our knowledge the fossil animal remains which have given so much cele- ity to the Burdiehouse limestone.

The magistrates of Stirling are at present boring for coal the Raploch, on the west shoulder of the Castle hill. The ring has advanced to 46 fathoms, and they intend to con- nue it to the depth of 72 fathoms. The borings have been 1 through the usual coal metals, as may be seen by the fol- wing table, exhibiting the names and thickness of the various rata through which they have penetrated.

otes, or Journal of Metals, in a bore at the Raploch, belonging to Cowan's Hospital founded within the burgh of Stirling, begun 9th Sept. 1834.

o.				Fath.	Feet.	Inch.
1.	Clay			3	3	0
2.	Gravel mixed with clay .			0	1	6
3.	Blaes			1	3	7
4.	do. mixed with iron . .	2	4			
	White freestone . .	1	1½			
	Grey do. . . .	2	4			
	Light grey do. . .		11½			
	Dark do. mixed with blaes .	1	4			
	Grey freestone . .		9½			
	Dark blaes . . .	3	8			
	do. mixed with iron . .	2	9			

No.					Fath.	Feet.	Inch.
	A band of iron			2½			
	Dark blaes		3	5½			
6.	do. do.		5	6½			
	A band of iron			3			
7.	Dark blaes		1	2½			
	A band of ironstone			11½			
8.	Dark blaes		1	7			
	Hard white stone			2½			
	Dark blaes	1	1	2½			
					7	0	
9.	Hard greystone					0	
	Dark grey blaes	1	4	9			
10.	do. do.	1	3				
	do. last 2 feet harder	1	2				
					4	3	
11.	Hard greystone				0	0	
12.	Dark blaes with thin hard bands		4	9½			
	do. do.		4	3			
	Dark hard stone				0	0	
	do. blaes mixed with bands			4			
	do. but harder		1	3			
					2	2	
13.	do. grey stone, very hard			9			
14.	do. do.			8			
					0	1	
15.	Dark blaes			2			
16.	Grey stone			3			
	White do.			2½			
	Hard bluish do.			8			
	Grey plies, hard and blue			7			
	Hard blue stone			7			
	Grey plies			11½			
					0	3	5
17.	White freestone				6	1	7
18.	Grey do.					1	4
	Dark blaes			4			
	A hard band			2½			
	Dark blaes		2	7½			
	do. mixed with foul coal		1	1½			
					0	4	
19.	Hard greystone				0	1	
20.	do. Dark blaes with 8 in. of a grey band				0	2	1
21.	Dark freestone				0	1	
22.	Hard grey band with 9 inches of blaes				0	1	
23.	Grey plies mixed with dark blaes and 2 in. of coal				1	0	
24.	Hard grey freestone				1	3	1
25.	Dark plies mixed with blaes				0	3	
26.	Hard clear coal				0	0	1
					32	3	
27.	Hard white stone				1	3	
28.	Dark blaes mixed with hard bands				4	4	
29.	Hard white stone				3	4	
30.	Dark blaes mixed with dark freestone				0	1	1
31.	A band of ironstone with 3 in. of greystone				0	0	
32.	Dark blaes, very hard, with 4 in. of hard greystone				0	2	
					46	2	1

30th Jan. 1835.

Explanation of the Terms.—Blaes is the local name for slate clay; white a
grey stones are sandstones; dark blaes, shale.

The Glasgow coal field is much more extensive than the Edinburgh, and has not been penetrated nearly to the same depth. Only the six uppermost beds of coal have hitherto been worked. The following table exhibits the succession of beds, from the surface to the first thin coal bed at the Clyde Iron Works, about four miles east from Glasgow:—

Beds.		Feet.	Inches.
1.	Reddish white sandstone,	4	1
2.	Red quartzy sandstone,	0	3
3.	Hard white slate clay,	0	1
4.	Soft blue slate clay,	5	3
5.	Hard siliceous slate clay,	0	4
6.	Soft blue slate clay,	7	8
7.	Ditto with vegetable impressions,	7	10
8.	Shale,	0	8
9.	Impure coal,	0	3
10.	Gray sandstone full of casts of trees,	3	6
11.	Soft blue slate clay,	8	4
12.	Shale,	0	1½
13.	Coal,	0	5½
		38	10

This first bed of coal, being only 5½ inches thick, is not workable. The uppermost workable coal, where nearest the surface, is at the depth of ten fathoms. It is four feet thick, and consists of *soft* coal, or *cherry* coal as it is called by the miners.

The second workable bed occurs eighteen fathoms below the first. It is three feet six inches thick, and consists partly of *soft* coal, and partly of *splint* or *hard* coal. It has much less lustre than the soft coal, is very tough, and breaks with a splintery fracture. It is not so easily kindled, but burns well, gives out much heat, and lasts longer than the soft coal. Hence it sells at a higher price.

The third bed of workable coal is four feet thick, and lies at the depth of six fathoms below the second. It consists, like the first bed, of soft coal.

The fourth bed of workable coal is three feet thick. It consists, like the preceding, of soft coal, and lies at the depth of twelve fathoms below the third bed.

The fifth bed of coal lies ten fathoms below the fourth. It is three feet nine inches in thickness, and consists almost entirely of splint coal.

The sixth or lowest bed of coal hitherto penetrated, lies 1½ fathom below the fifth bed. Its thickness is seven feet, including some thin bands of stone which occur in it. This be consists of a caking coal, similar in its properties to the Newcastle coal. It is at present scarcely worked, the demand fc this kind of coal not being great.

Thus, the whole depth of the Glasgow beds hitherto worke amounts only (including the coal) to 61 fathoms 4¼ feet, 370¼ feet. This shallowness is probably the reason wh these pits are very seldom obnoxious to fire damp.

The Glasgow coal field dips on both sides to the Clyd which, of course, constitutes the deepest part of the basin which the coal measures have been deposited. About s miles north-east from Glasgow a section of the coal measur is exposed by the Garnkirk railway. Here they dip to t north-east. This change of direction has been probably pr duced by a basalt dyke, which traverses the field on the w side of Bedlay.

At Hurlet, about five miles south-west of Glasgow, the occurs a single bed of coal between five and six feet thic It has been worked for at least two hundred years. The b of coal is situated twenty-eight fathoms below the surfac The roof is mountain limestone and the floor shale. T connexion between the Hurlet coal and the Glasgow beds not well understood. They are separated from each other b a dyke which has deranged all the strata. But it is certainl situated greatly below the Glasgow beds. Its depth belo the sixth bed is calculated, by the best coal engineers abou Glasgow, to be more than two hundred fathoms.

On the north side of the Clyde, the farthest west coal p is at Duntocher, (about eight miles west from Glasgow,) i the parish of Old Kilpatrick. Only one bed of coal is know situated twenty fathoms below the surface. This bed is b tween four and five feet in thickness, and consists, like the Hu let coal, of a caking coal a good deal mixed with iron pyrite The roof of the coal consists of a bed of mountain limesto between four and five feet in thickness, and full of the usu shells which distinguish that formation. The other co metals, namely, beautiful sandstone, shale and fire clay alte nating, constitute the beds between the limestone and t surface. The coal dips to the south-east, and doubtless li below all the Glasgow beds.

The principal species collected by my son, from one Mr. Dunn's limestone quarries, were the following:—

Producta Scotica of Sowerby.
——— longispina, S.
——— fimbriata, S.

And three other species which seem to be new, or at least are not figured by Sowerby.

Terebratula, 4 species.

Spinifer, the same species as was observed in the limestone at Swinridgemuir (noticed below), and two other species.

Unio, one species.

Dentalium, one species.

With many encrinites and some other corallines.

Neither has the position of the Johnstone beds, relative to the Glasgow seams, been determined. There was at one time a bed at Johnstone nearly eighty feet thick, but it has been worked out.

The annual consumption of coal in the Glasgow market, taking in what is exported, amounts to about 750,000 tons. Besides this, about 120,000 tons of coals are consumed in the iron works in the neighbourhood of Glasgow; so that the whole annual consumption amounts to about 870,000 tons.

The coal metals continue with little interval from Johnstone to the sea coast at Saltcoats; but the country is so intersected with trap dykes, which heave the beds (always to the east), that the connexion between the coal beds in Ayrshire and those of Glasgow has never been traced. At Swinridgemuir, in the parish of Dalry, the beds dip to the east by south. There are three beds of coal, the two uppermost not more than twenty-two inches or two feet thick, and the highest of these crops out behind the house of Swinridgemuir. Under it lies a bed of limestone, which when thickest is not less than twenty feet, but it thins out to four feet or even less. Between this limestone and the lowest workable bed of coal known is twenty-one fathoms of sandstone, shale and slate clay. The coal is from four to five feet thick. One trap dyke heaves this coal field eighteen feet, another about sixty-eight feet. In these cases the portion of the field on the west side is always the lowest.

The uppermost portion of the limestone bed is full of entrochites, caryophyllia and productas. I think, also, that I observed a new species of spinifer, and a nautilus seemingly also a new species, with some obscure traces of a pecten or some analogous shell, together with the producta Martini. In the slate clay were numerous casts of nucula gibbosa of

Fleming, and a specimen or two of nucula attenuata, Bellerophon Urii and euomphalus catillus. In the limestone there was the impression of a leaf, which is probably new. It had some slight resemblance to a fucoides, only it had a middle rib.

About three miles to the west of Dalry is situated Beadlan-hill, round backed, covered with grass and elevated 903 feet above the level of the sea. This hill, or at least its upper part (which alone I was able to examine), is a mass of basalt. In this rock, some hundred feet below the summit and very near the surface, there is a bed of coal four feet thick dipping to the north-west at an angle of 45°, though the regular coa beds at the foot of the hill dip to the east by south.

Both the roof and floor of this coal is basalt. The coa is without lustre, has a brown colour, does not stain the fingers is uncommonly hard and exceedingly tough. Its specific gravity is 1·317. It burns with a lively flame for some time, an leaving a matter having the shape of the piece, and whic gradually wastes away with a strong sulphureous smell, leaving 25·77 per cent of a red earthy residue, composed of silic and oxide of iron, with a little lime and alumina. This coa differs in appearance from any that I have seen, and, were not for the great proportion of earth which it contains, woul probably answer for manufacturing gas. Its structure is slat I observed some vegetable impressions in it, differing fro any thing hitherto described among fossil vegetables in coa as they seemed to be *fucoides*. The coal at Fairhead, in th north-east point of Ireland, is similarly situated. Whether be similar in its nature to the Beadlan coal I have never ha an opportunity of judging.

The mountain limestone at Muirkirk, in Ayrshire, contain the following shells:—

Producta costata, Sow.,	Nucula attenuata,
——— hemispherica, Sow., (a gigantic specimen,)	Encrinites and cariophyllia,
	Lepidodendron Harcourtii.

The Campsie hills, which bound the Glasgow coal field the north, consist partly of trap rocks and partly of coal measures. The lower part of these hills consist of alternate be of slate clay, sandstone, shale and limestone. There occurs beautiful variety of greenstone in these hills composed *labradorite*, in large crystals, and hornblende. This kind greenstone, which has not yet been described by geologis is rather abundant in the neighbourhood of Glasgow.

great portion of the hills on the south side of Paisley consists of it. Large blocks of it may be seen on the road near Gleniffer.

To enable the reader to understand the situation of the coal fields in the north of England, it will be requisite to give a short sketch of the nature of the country. The whole north of England is traversed by a chain of mountains which the Romans distinguished by the name of the *Penine Alps.* It may be observed branching off from the transition chain of mountains which cross the south of Scotland, but it does not rise to any considerable height till it reaches Geltsdale forest in Northumberland, near to which is Crossfell, the highest summit of the chain, and the highest mountain in England. Thence it proceeds south by Stainmoor forest to form the western moorlands of Yorkshire, and the elevated country between that county and Lancashire. Farther south it enters Derbyshire and Staffordshire, forming the High Peak of the one, and the moorlands of the other, and the chain finally expires on the banks of the Trent. Though this range of hills contains no coal, yet it is composed of rocks obviously connected with the coal measures.

The lowest rock of all is a *red sandstone.* It has been observed only towards the northern part of the chain, forming the fundamental rock beneath the western escarpment of the Crossfell range. It may be observed likewise near Ingleborough in Yorkshire. The mountain limestone occurs extensively towards the north of the chain, occupying the middle region of the hills, especially on their western escarpment. A zone of mountain limestone is here detached from the Penine chain, and encircles the transition mountains of the Cumberland group. The upper part of the Penine hills consists chiefly of a coarse sandstone, called by the English geologists *millstone grit,* mixed with shale.

Thus the uppermost part of these mountains consists of coal measures, and the undermost of strata which lie immediately under the coal beds. Now this Penine chain is in some measure environed by coal fields—at least they occur on the east, west and south sides of it.

The first and most important of these is the great coal field of Northumberland and Durham. It begins at the mouth of the Tweed. Indeed, the coal measures may be traced on the sea shore about half a mile beyond Berwick on the north. A small portion of them is again exposed at Lennel braes on the north bank of the Tweed, about two miles east of Coldstrean Various coal pits exist near Tweedmouth, and extending few miles to the south. There then occurs an interval more than twenty miles, in which no coal has been foun This important deposit makes its appearance again at t Coquet river and extends almost to the Tees, constituting length of about fifty-eight miles, with a breadth of abo twenty-four. The lowest part of this coal basin is a li drawn north and south through Jarrow, a colliery about fi miles from the mouth of the Tyne. The coal measures o both sides of this ideal line dip towards it, and of cour crop out as we proceed east or west. Those on the east, they ever existed, have been destroyed by the sea, exce those which still exist beneath its surface.

The beds belonging to the Newcastle field are eighty-tw in number. Twenty-five of these are beds of coal, the r maining fifty-seven consist of alternating beds of sandsto and slate clay. Many of the coal beds are too thin to worked. The two most important of them have received t names of the *high main* and the *low main;* the former is s feet thick, and the latter six feet three inches. The hi main is seventy-five fathoms below the surface, the low ma is about sixty fathoms under the high main. Between the two beds occur eight strata of coal, one of which is four fe and another three feet thick. The others are insignificant.

The quantity of coal raised annually in this field is i mense. It supplies London and the whole south and ea coasts of Great Britain, from the north of Scotland to Devo shire. From the county of Durham alone 1½ millions chaldrons are shipped annually. Certainly the whole qua tity annually exported greatly exceeds two millions of cha drons or three millions of tons; yet such is the quantity coal in the district, that at the present rate of consumption is calculated that it will last for a thousand years to come.

The beds of millstone grit, shale and *craw coal* (as it called), lying under the Newcastle beds, amount to 152. (these, ten beds are coal, most of them thin, and all inferior value to the Newcastle coal.

There are a few detached coal fields in the north of Yor shire. They are of limited extent, and the coal is seldo more than twenty inches thick. These little basins are pr vincially called *swilleys.* They seldom exceed a mile or mile and a half in length, and none of them has been worke

But at the southern extremity of Yorkshire, and extending into Nottingham and Derbyshire, there is situated a great coal field, scarcely inferior in importance to that of Newcastle itself. It occupies an area nearly triangular, but with a truncated apex; the base, or broadest part, being at the northern extremity, and the apex, or narrowest part, at the southern. Its greatest length, from Leeds to Nottingham, rather exceeds sixty miles; while its greatest breadth, from east to west, is about twenty-two miles.

The position and dip of the beds is the same as that of the Newcastle coal field. The beds crop out to the west and dip to the east. The strata of coal amount to thirty, varying in thickness from six inches to eleven feet. The whole thickness of coal is stated by Mr. Bakewell as amounting to seventy-eight feet. The beds of slate clay and shale are numerous; those of sandstone amount to twenty, and some of them are very thick. The lowest of these beds is termed *millstone grit*, and below it no workable coal is found.

This field is traversed and dislocated by an immense *fault*, proceeding from near the termination of the magnesian limestone range on the south northwards in a zigzag direction, on the western side of that limestone, quite into Yorkshire. Respecting the size and contents of this *fault* we have no accurate information; but the beds of coal on the west side of it are so dislocated, that it is difficult to connect them with the intervening strata, so as to form an accurate conception of their number and relative position with respect to each other. The best account of this coal field that I have seen will be found in Mr. Farey's *Mineral Survey of Derbyshire.*

To the west of this great coal formation in North Staffordshire there are two detached coal fields, namely, that of Cheadle and that of Newcastle-under-Line where the potteries are situated.

The Cheadle coal field appears to consist of an insulated basin, reposing, according to Mr. Farey, upon millstone grit.

The Pottery coal field occupies a triangular area, the two sides of which are each about ten miles in length, and the base, in the middle of which Newcastle-under-Line is situated, about seven miles long. From the two sides the beds dip towards the centre of the area. The lowest bed is millstone grit, which seems to rest on mountain limestone.

The Manchester or South Lancashire field begins in the north-western parts of Derbyshire, and ranges thence to the south-western parts of Lancashire; forming a kind of crescent with Manchester nearly in the centre. The distance between the extremities of this crescent is about forty miles. Generally speaking, the beds crop out towards the south, where they may be seen lying over the millstone grit. But great disturbances interrupt the regularity of this disposition. In the first place, what may be called the south-eastern horn of the crescent, forming the portion of the coal field which lies within Derbyshire and Cheshire, bifurcates at the village of Disley in the latter county, being divided into two branches by an intermediate ridge or saddle of millstone grit. The eastern branch forms a trough of which the strata crop out on both sides against the millstone grit. This has been called the Goyle trough, from a small river of that name which runs through it. The extent of it is about fifteen miles from Disley to near Mearbrook in Staffordshire.

The western branch of the bifurcation is not so regular, owing to numerous *faults* which have altered its position. These coal beds contain more than fifty seams of coal in a few hundred yards' sinking.

Respecting the northern and far more important part of this coal field, which occupies a considerable portion of the southern division of Lancashire, I am not aware that any accurate details have been given to the public.

There is another coal field of small extent in the north of Lancashire, situated half way between Lancaster and Ingleton. It seems to form a small insulated basin reposing on, and surrounded by, millstone grit.

The last coal field connected with the Penine Alps that requires to be mentioned is that of Whitehaven. It lies on the sea shore, and extends from the promontory of St. Bees, where a good section of the coal beds and the superincumbent rocks may be seen, about twenty miles north. The number of beds cut through in this field is 117. Of these, seventeen are coal. The rest are sandstone, slate clay and ironstone. The greatest depth of the mines is 110 fathoms.

If we reckon the millstone grit and the mountain limestone as constituting a portion of the coal field, then we may say that a great coal formation extends without interruption from Berwick to Nottingham, from Nottingham to Liverpool, to the Solway Firth, and from that to Berwick, constituting a length of about 200 miles, and a breadth of about 90 miles. But as a great portion of this tract consists of millstone grit containing very little coal, and of mountain limestone containing none at all, it seemed better to notice the different coal fields separately.

The coal fields in the central districts of England come now to be noticed. Though of no great extent they are important on account of the manufacturing population which they supply with fuel. This part of England consists of new red sandstone, through which detached coal beds rise in different places like so many oases.

The first of these is the Ashby-de-la-Zouch coal field, which occupies an irregular area of 10 miles by 8, having the town of Ashby-de-la-Zouch nearly in its centre. It extends nearly to the transition country of Charnwood forest in Leicestershire. The deepest coal pit in this district is 123 fathoms. Six beds of coal are known, the lowest of which has a thickness of from 15 to 21 feet.

This coal field is flanked on the north-west by a line of detached mountain limestone of a remarkable character. This limestone contains magnesia, but is known to be mountain limestone by the fossils found in it. There are eight of these detached limestone points, each occupying but a few acres in extent, surrounded, and as it were, insulated by overlying masses of new red sandstone.

The second central English coal field is in Warwickshire. It extends from Tamworth, in Staffordshire, to about 3 miles east from Coventry, a length of about 16 miles. Its average breadth is about 3 miles. The beds crop out to the east north-east, the inclination becoming more and more rapid towards the eastern edge of the field, where it in several places exceeds an angle of 45° with the horizon. On the west side it decreases to one foot in five. The lowest bed exposed is millstone grit. The principal works are near the southern extremity of the field, at Griff and Bedworth. At Griff four beds of coal are worked; the depth of the first bed is 117 yards, and the principal seam is 9 feet in thickness. The Bedworth works are upon the same beds; but here the first and second coal seams run together, and constitute one 15 feet thick.

The third central coal field is the one which supplies the manufacturers of Birmingham and the immense iron works between Dudley and Wolverhampton, with fuel. In length it extends about 20 miles, from near Stourbridge on the south-west, over Cannock chase to Beverton, near Badgeley on the north-east. Its greatest breadth near Dudley, may be about 4 miles. Its superficial area has been found by actual survey, to equal 60 square miles. The northern portion from Cannock chase to near Darlaston and Bilston, affords many coal seams, of 8, 6, and 4 feet in thickness. The southern portion extending thence to near Stourbridge, is about seven or eight miles in length and four in breadth.

This field lies over transition limestone, no red sandstone, mountain limestone, or millstone grit, intervening between the coal beds and the transition rocks. The beds in this field amount to sixty-five, all of which have been cut through to a depth of 940 feet. There are eleven beds of coal, but only the one called *main coal*, 30 feet thick, and constituting the sixth bed, is worked. It lies 315 feet below the surface. The beds dip to the south and gradually crop out as we advance north. Hence it happens, that in the north part of this field the *main coal* is wanting, and those only are worked which lie below it.

Having described the coal fields in the north, east, and central parts of the island, let us attend to those in the western parts of Great Britain. They are disposed round the great transition district of North and South Wales, and may be conveniently distributed into three sets:—1. The north-western; 2. the western; and 3. the south-western.

1. *North-Western Coal Beds.*

Coal is wrought in a valley of the island of Anglesey, which runs parallel to the Menai straits; but I have no information respecting the extent or importance of this coal field.

The principal north-western coal formation is in Flintshire. It begins at Llanossa, near the western cape of the estuary of the Dee, and extends south to near Oswestry in Shropshire, a length of about thirty miles, but the breadth is not great. These coal measures repose upon mountain limestone, which rises to day on the west side of the coal basin, and consitutes a tract of some extent, skirting indeed (but with intervals) almost the whole transition rocks of Wales. Over this limestone lie beds of shale and sandstone, corresponding with the shale and millstone grit of Derbyshire. The coal is of different thickness, from three quarters to five yards. The beds dip from one yard in four to two in three. They sink below the estuary of the Dee, are discovered again on its opposite side on the south of the peninsula of Wiral in Cheshire, where they finally sink below the new red sandstone. Possibly they may continue under it to the Lancashire coal field.

2. *Western Coal Beds.*

The western coal fields are three in number; namely, 1. That in the plain of Shrewsbury; 2. Coalbrookdale coal field; and 3. the coal fields of the Cleehills and Billingsley.

1. The plain of Shrewsbury is skirted by transition hills; it is itself mostly covered with beds of new red sandstone, through which are scattered many small patches of coal beds.

2. The Wrekin, a very conspicuous hill in Shropshire, is composed of trap. It constitutes one of a series of low hills that run on the east side of the plain of Shrewsbury. A few miles to the eastward of this chain, lies the important coal field of Coalbrookdale. This field is about six miles long, from Wambridge to Coalport, on the Severn. Its greatest breadth is about two miles.

The coal measures rise west north-west, at an angle of about 6°. On the eastern side, to which they dip, they are succeeded by the great new red sandstone district. The beds are those which usually belong to the coal measures. Those which have been cut through are 86 in number. The deepest coal pit, namely, 729 feet, is at Madely. The sandstones, which make part of the thirty uppermost strata, are fine-grained, very micaceous, and often contain thin plates or minute fragments of coal. The 31st and 32d strata are coarse sandstones, entirely penetrated by petroleum. The thickness of both together amounts to 15½ feet, and they furnish the supply of petroleum that issues from the tar spring at Coalport. At the depth of 430 feet, occurs the first very coarse sandstone or grit. Its thickness is about 15 feet. The next bed of sandstone deserving notice, is at the depth of 576 feet. It is about 18 feet thick, fine-grained, and very hard, and is often mixed with a little petroleum. The colliers call it *big flint.* The lowest sandstone, called *little flint*, is the 85th bed, and is about 15 feet thick. The lowest portion of it is very coarse and full of quartz pebbles. The upper part is fine-grained, and sometimes is rendered very dense and hard by an intimate mixture of iron ore. It occurs at the depth of 705 feet.

One bed of clay porphyry occurs, 9 inches thick and 73 feet from the surface. It is an indurated clay of a liver-brown colour, with intermixed grains of quartz, hornblende, felspar.

The clay beds are sometimes compact, dull, and smo they are then termed *clod.* Sometimes they are glossy, tuous, and slaty, when they are called *clunch.* They co compressed balls of clay ironstone.

The beds of iron ore are five or six in number. The lie in the indurated clay, and consist of balls or broad masses. Essentially they consist of carbonate of iron.

The slate clay, called by the miners *basses*, is of a b black colour and slaty texture. It usually contains py and is always either mixed with coal or combined with p leum.

The first bed of coal occurs at the depth of 102 feet the surface. It is only 4 inches thick, and is very sulphur Nine other beds of the same nature, but somewhat thi lie between this and the depth of 396 feet. They are c *stinking coal*, and are employed only in the burning of The first bed of coal that is worked, is 5 feet thick, and o at the depth of 496 feet. Between this bed and the *big* are two beds of coal, one 10 inches, the other 3 feet t Between the *big* and the *little flint*, which are about 100 apart, lie nine beds of coal of the aggregate thickness of a 16 feet. Beneath this, and constituting the lowest bed o whole formation, is a sulphureous 8 inch coal. Thus whole beds of coal amount to 23, but only two or thre them are worth working.

3. A few miles south from the Coalbrookdale coal fiel the hills of Brown Clee and Titterstone Clee. Upon a number of small detached coal fields are distributed.

3. *South-Western Coal Fields.*

This division includes the three following important fields:—1. The grand south Welsh basin; 2. the Fore Dean basin; and 3. the south Gloucester and Somerset b All these coal fields are close related, not merely by posi but by all resting on a common basis of old red sandston by the general analogies of their structure throughout. strata near the edges of the basins are often highly incli and are partially covered and concealed on the south-east of the great basin of South Wales, and throughout a portion of that of South Gloucester and Somerset, by hori tal deposits of more recent formations.

1. The great coal field of South Wales, extending from Pontipool to St. Bride's bay, south of St. David's head on the west, is situated in a large limestone basin. The limestone crops out all round the coal, except where its continuity is interrupted by Swansea and Caermarthen bays. The deepest part of the basin is in the neighbourhood of Neath, which is near its centre. And below Neath, or a little to the west of it, the lowest strata of coal are nearly 700 fathoms lower than the out crop of some of the inferior strata, in the more hilly parts of the district. The bed of coal which is nearest the surface, lies (near Neath) about 60 fathoms beneath it, and rises to it about a mile north and south, and also a few miles east and west of the deepest part of the basin. We may imagine the inferior beds of coal rising to the surface all round the out crop of the superior stratum. If a line be drawn from Pontipool on the east, to St Bride's bay on the west, it may be said that all the beds of coal on the north side of that line crop out on the north of it; and so also those on the south, except near Pontipool, where they rise towards the east.

There are twelve beds of coal from 3 to 9 feet thick, making together 70½ feet; and eleven others, from 18 inches to 3 feet, making 24½ feet, amounting altogether to 95 feet of workable coal, besides numerous others from 6 to 18 inches thick. This coal field occupies about 100 square miles. It contains 100,000 tons of workable coal per acre, or 64,000,000 of tons per square mile; or, altogether, the enormous quantity of 6400,000,000 tons of coal. This at the rate 5,000,000 tons per annum, (which is much more than the consumption in the Newcastle coal field), would last little short of 1,500 years.

The coal on the north-western side of the basin is what is termed *stone coal*, a kind of anthracite. The small of this, called *culm*, is used by the iron smelters and for burning lime.

The *lower* part of the coal series, as worked at Merthyr Tydvil and the neighbourhood, is distinguished by the predominance of shale; the *upper* by the predominance of a coarse grit of loose texture, abounding with specks of coaly matter, and agreeing with the rock called *pennant*, in Somersetshire. These beds are often slaty, sometimes sufficiently so to be employed as tiles. A great thickness of them separates the lower from what may be called the upper coal series, and it is of this rock that the summits of all the principal mountains in the interior of the basin consist. The lower series contains numerous strata of coal and sixteen of ir stone. This ore exists both in continuous beds and in tached nodules. It is principally found in the lower seri and some of its most valuable beds occur beneath the low coal. The beds alternating with the coal and ironstone the lower series consist almost exclusively of slate clay; tween it and the limestone on which the coal formation re millstone grit is often, but not always, interposed. upper coal series has not yet been accurately described.

The inclination of the strata is much more rapid on south edge of the basin than on the north; being often an angle of 45° or more, while that on the north is gener under 10°.

On the western termination of the basin in St. Bride's the strata exhibit the most extraordinary marks of confu and derangement, being vertical, and twisted into every po ble form of contortion.

This coal field is traversed by *dykes* or *faults*, generall a north and south direction, which throw all the strata f 50 to 100 fathoms up or down. They are usually filled clay, but Mr. Townsend mentions an enormous fault, m fathoms thick, filled with fragments of the disrupted st which traverses the colliery of Lansamlet, near Swan effecting a rise of 40 fathoms in the strata.

2. The coal basin in the forest of Dean occupies the w of the forest tract. It ranges round Colford as a centre, is about ten miles long from north north-east to south so west, and about six miles broad. All the beds dip unifor towards the centre of the basin. Exterior ridges of moun lime and old red sandstone enclose the coal measures doubtless pass under them.

The thickness of the coal measures is 500 fathoms, cont ing about 26 beds of coal.

3. The coal basin of Somersetshire and south Glouce shire occupies an irregular area, of which the longest dia ter, from near Iron Acton, on the north, to Coalford at foot of the Mendip hills, on the south, is near 25 miles. shorter from the Newton collieries, near Bath, to thos Bedminster, near Bristol, is about eleven miles. The co of the river Avon nearly coincides with this diameter, divi the coal field into almost equal portions. At the north- and west the strata dip towards the centre of the basin; at Coleford, near Mells, on the south, where they abut ag

e Mendip hills, the stratification is much deranged, becom- g vertical, and frequently thrown backwards and bent into e form of the letter Z.

This coal basin is very interesting to the geologist, because is covered by some of the newer formations, which have en penetrated and their unconformable position ascertained. hus the relation between the coal beds and the newer formations has been determined. Several of the formations low the coal are also exposed to view. The order of the ds, beginning with the lowest, is as follows:

reywacke,
ransition limestone,
ld red sandstone,
Mountain limestone,
Coal measures.

The formations above the coal measures, in the order of eir position, are

New red sandstone, { Dolomitic conglomerate.[*]
  Red sandstone.
  Red marl.
Lias,
Oolite.

he Mendip hills, which bound this coal basin on the south, e composed of mountain limestone.[†]

There is a small coal basin near Wells, as appears from mith's map, but I have met with no description of it.

Having finished the account of the coal measures in Great ritain, let us now turn our attention to Ireland.

Ireland may be considered as an island, nearly surrounded y primary or transition mountains, including a great central ea filled with red sandstone, mountain limestone, and coal easures. The Irish coal districts are four in number.

1. The Ulster coal district, in the north of Ireland, is small extent, being almost limited to the trap mountain of Fair- ead, under which it lies.

2. The Connaught coal district occupies an extensive tract Leitrim, in the middle of which Loch Allen is situated.

3. The Leinster coal district is situated in the counties of ilkenny, Queen's and Carlow. It also extends a short way to the county of Tipperary; namely, as far as Killenaul. his is the principal coal tract in Ireland; it is divided into

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[*] The substitute for the magnesian limestone inthe north of England.

[†] For a full and instructive account of this important coal basin the ader is referred to the description of it by Buckland and Conybeare, in e *Memoirs of the Geological Society* (second series), i.

three basins separated from each other by mountain limestone, which not only surrounds but underlies the whole formation.

4. The Munster coal district occupies a considerable portion of the counties of Limerick and Kerry, and a large part of the county of Cork. It is the most extensive in Ireland, though hitherto very little coal has been extracted from it. According to Mr. Weaver much of these coal measures are in the *transition* formations; a fact which, if confirmed, will overturn many of the theoretic opinions entertained about the state of the globe at the time when the coal beds were deposited. An accurate survey of this part of Ireland would be a valuable present to the science of geology.

We may now take a cursory view of the coal tracts on the continent.

1. There occurs a small coal tract at Helsingburg, at the Sound, not far from the southernmost point of Sweden. It extends about thirteen miles along the sea coast, and its greatest breadth may be about nine miles. This tract consists of the usual coal measures, sandstone, slate clay, shale and coal. There are two beds of coal, the uppermost is 1 foot thick, the undermost 2½ feet. The coal mine which was worked at Höganäs in 1812, was 80 fathoms deep. It was mined for some time unsuccessfully by a Swedish company. Some years ago Mr. Bald was employed to survey it; he found the sandstone of so spongy a nature that it was impossible to drain the mine. By his advice the workings were abandoned.

From the fossils found in these coal measures, and from the description of the rocks of which they are composed, there can be no reasonable doubt that these coal deposits are situated in the *lias*, as is the case at Whitby and in Sutherland.[*]

Coal measures exist in the island of Bornholm, which is situated in the Baltic, on the east side of Scania. From the description of Hisinger and the fossils found in that part of the island, it is obvious the coal measures here also lie in the great oolitic formation.

2. Coal probably exists in considerable quantity in Spain though no attempts have been made to work it. Eight different localities in Catalonia, three in Arragon and one in New Castile, are cited, where coal exists. But we know nothing of either the extent or depth of these coal basins.

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[*] See Köng. Vet. Acad. Handl., 1820, p. 108.

Since the absurd prohibition of mining, which existed so long in Spain in favour of America was removed by the Cortes in 1820, the inhabitants of the mining districts of that country have been roused into uncommon activity, and several collieries have been opened in different parts of the kingdom. In the neighbourhood of Oviedo, in the Asturias, very rich coal mines are worked, chiefly for the metallurgic establishments of Andalusia. Another coal mine near the river Avilis, and consequently more favourably situated for exportation, has been more lately opened. And the small coal field of Villa-Nueva-del-Rio, eight leagues above Seville, supplies fuel to the steam-boats which ply between Seville and Cadiz.*

3. France possesses many considerable coal tracts, and has of late years been fully aware of their importance. Great assiduity has been displayed in endeavouring to apply these mineral riches to the smelting of iron. But a circumstance, apparently trifling in itself, has hitherto prevented the French iron works from thriving. In France the coal and the iron ore do not occur together, as they do in Britain.† Hence they are obliged, at a great expense, either to carry the ore to the coal,or the coal to the ore.

There occurs a small coal field at Litry, on the south-west of Bayeux, in the western part of Normandy, just where the transition tract of the Cotentin terminates. This tract, in point of situation, is analogous to that of the south-western coal fields of England. The coal metals repose immediately on transition formation, but in an unconformable position. Somewhat farther south between Angiers and Nantes, where the Loire forces its way through the transition chain to the sea, another more extensive, though not large, coal field occurs.

In the centre and south of France several coal tracts occur in the valleys interspersed through that extensive primary country. These occupy chiefly the valleys of the Loire, the Allier, the Creuse, the Dordogne, the Aveyron and the Ardeche, between ridges proceeding from the primitive centre group, connected with the Cevenne; and also on the south-east, between the Cevenne and the Rhone. In these places the coal beds repose immediately on the primary formations.

In the north-east of France, and in Belgium, a very consi-

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* Ann. des Mines (third series), v. 184.

† The Newcastle coal beds constitute an exception. No ironstone is found in them. Hençe the reason of the small number of iron works established in that great coal country.

derable coal tract exists. It extends from Hardinghen, nea Boulogne, in nearly an eastern direction, as far as Eschweiler, beyond Aix-la-Chapelle, a length of about 200 miles. Indeed, several of the coal districts in the north of Germany may be considered as prolongations of it.

This coal field is covered by the green sand formation, and lies immediately on the transition formation, and is 8202 feet below the level of the sea.*

On the east and north, the great deposits of chalk, and the strata above the chalk, skirt and partially overlie this tract. On the south, it is bounded by the transition ridges which occupy the forest of Ardennes, overhang the magnificent defile of the Rhine, from Bergen to Bonn, and thence extend to the Westerwald. This tract does not consist of a single coal field, but of many isolated and basin-shaped deposits of coal measures, encircled by mountain limestone, and old red sandstone. It bears a striking resemblance to the coal districts in the south-west of England.

The most westerly point of this great chain of coal basins is at Hardinghen, in the great denudation exposing the beds below the chalk, which comprises the Boulonnais on the French side of the channel, and the Weald of Kent and Sussex on the English side. The coal mines and quarries of mountain limestone, which occur at Marguise, are situated at the very foot of the escarpment of the surrounding chain of chalk hills. For the outcrop of all the intermediate formations crosses this part of the denudation to the south, and, as it were, withdraws to expose the coal. Indeed, to the west the coal is worked at several places within the general limits of the overlying chalk formation.

The environs of Aniche, near Douay, and of Monchy le preux, near Arras, present deposits of this nature. The mines surrounding Valenciennes are still more extensive. In the neighbourhood of Mons, Charleroy, and Namur, in a tract surrounding Liege, and close to Eschweiler, on the east of Aix-la-Chapelle, very considerable coal fields are worked.

To the east of this place, the more recent formations intrude upon and conceal the coal, till you cross the Rhine a little to the north of Bonn. Then these newer formations again recede to the north, and an extensive coal field occurs along the small river Ruhr, a little above its junction with the Rhine. On

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* Brongniart, Tableau des Terrains, &c., p. 276.

the south, the beds of this coal field describe the segment of a circle, cropping out against alternations of limestone, shale, and old red sandstone, which separate them from the regular transition slate. On the north they are bounded by the overlying and more recent deposits.

Somewhat to the north of this district of transition rocks, coal fields again occur between the Rhine and the Moselle, in the northern parts of Lorrain; first between Sarrebruck and Sarrelouis, on the river Sarre; and, secondly, near Waldmohr, on the banks of the Glane. But I have never met with a good description of these coal fields. From Keferstein's account, the beds are extremely contorted and dislocated. Masses of unstratified trap rocks are interposed among the coal measures. Agates abound in the amygdaloid. Quicksilver occurs both in the porphyritic conglomerate, and in the coal sandstone.

Coal also occurs on the west side of the Vosges mountains, which form the limit between Alsace and Lorrain.

4. In the south-west and south of Hanover, there occurs an extensive coal district, between Osnabruch and Hildesheim. It is probably a continuation of the great coal tract in the Netherlands.

There is an extensive coal tract on the east side of the Hartz mountains, which has been described by Keferstein. The coal measures immediately succeed the slate mountains of the Hartz; near the east end of which they present themselves in three places; 1. The Opperode district; 2. The Ilefield district; 3. The Petersbirge district. The two first lie immediately on the slate, and form a portion of the Hartz chain. The third constitutes an insulated district in the Suale Kriese. The coal measures present the usual alternations of shale, sandstone, and some limestone beds, containing marine fossils. Three beds of coal are sometimes found. A good deal of porphyry occurs in the Ilefield and Petersbirge districts. Its relation to the coal beds has not been well made out. From Humboldt's account, it does not seem to form true beds; but to have been introduced in the same way as the trap rocks into our coal fields.

There occurs a small coal field between Dresden and Freiberg, near the Weisseritz river, which, from the nature of the country, would seem to rest on primary rocks, as is the case in France. But the principal Saxon coal district lies along the course of the Zwickau, between Leipsic and the Erzgebirge. In this district, porphyry prevails; and it would see in some places to be associated with, and to alternate wit the coal beds. Coal occurs near Zwickau at Schonfeld, a at Planenschen grund near Dresden. This district is su posed to have a subterranean connexion with Petersbir district, in the Hartz.

Coal occurs in two different parts of Bohemia, at Pilsen a Waldenburg.

There is an extensive coal district in upper Silesia, inclu ing the following towns:—Pless, Freystadt, Troppau, Jage dorf, Kosel. It lies partly in Silesia, and partly in Pola In the former country, it exhibits coal only; in the latter, c and porphyry. The coal beds repose immediately upon t slate mountains of the Sudetergebirge. The strata are e vated on approaching that chain, but become more horizon as they recede from it. The coal measures are covered by t porphyry, which in its turn supports the alpine or magnesi limestone. The coal measures pass by such gradual transiti into the greywacke, on which they repose, that, according Keferstein, it is difficult to ascertain the exact demarcati between them. Hence the position of this coal seems to similar to that in the south-west of Ireland. The usual str of the coal measures present *grits*, or coarse sandstones various textures; millstone grit, shale, with nodules of cl ironstone, and mountain limestone. There are numerous be of coal, and some of them of considerable thickness.

5. There is a coal district at Balligorod and Rosocky, ne Sanok, in Austrian Poland, upon the north side of the C pathian mountains.

6. Another coal tract is said to occur in Hungary, Funfkirchen, on the borders of Sclavonia. The order of be beginning at the surface, is as follows:—

1. Red porphyry,
2. Red grit,
3. Greenstone,
4. Several varieties of grit,
5. Coal,
6. Carbonaceous grit,
7. Shale and fetid limeston
8. Slaty coal grit,
9. Coarse coal grit,
10. Black limestone.

The uppermost of these beds evidently belong to the ne red sandstone, which lies immediately over the coal measur

7. In Russia, an extensive coal tract occurs at Toula, the south of Moscow, where the great Russian iron works a established. About the year 1816, the Emperor Alexand gave a large salary to a gentleman from Whitehaven, a pra

tical coal mining engineer, to superintend the working of this coal. The coal was worked successfully for some years; but at last suddenly abandoned, because it was found that the Russians could not be prevailed upon to purchase this coal, after it had been dug up.

8. Coal is said also to occur in the Crimea, and near the Uralian mountains, not far from the source of the Chusova.

9. There can be little doubt from the abundance of naphtha and petroleum in various parts of Turkey and Persia, that coal tracts of considerable extent exist in these countries; though no attempts have been made by the inhabitants to avail themselves of the mineral riches which their country is capable of furnishing.

10. There is a coal tract upon the Ganges, in Bengal, about two hundred miles above Calcutta. This coal is worked and supplies the manufactories in Calcutta with fuel. No description of these coal measures, so far as I know, has been published.

11. Coal has also been discovered in the district of Cutch, to the north of Bombay.

12. On the east coast of New Holland, about fifty miles north of Port Jackson, there is a coal field, the strata of which are laid open by the section of the cliffs at the sea shore. This coal has been worked for some time, and was carried to Calcutta till superseded by the discovery of coal on the banks of the Ganges. It supplies all our settlements in Australia with fuel. The bed of coal worked is about 40 inches in thickness, and is about 100 feet below the surface of the earth. It has been suspected, from the fossils found in these coal measures, that they belong rather to the lias than the independent coal formation; but the coal measures are traversed by trap dykes, in the same way as our own fields.

If we now turn our attention to the continent of America, we shall find that the inhabitants of the new world have been furnished with large quantities of this subterraneous fuel, which, in future ages, after the country has been fully peopled and stript of its superfluous timber, will be found of immense importance.

13. A remarkable coal district occurs in Pennsylvania, and extends about a hundred miles north by east, running parallel to the Blue Mountains, which traverse that country from the Susquehanna to the Lehigh mine, then bending north and

afterwards north-east. The tract of country in which it occurs is transition; but the coal measures, from the description of them by Mr. Cist, appear to be similar to those which occur in this country. The American coal is an anthracite, which burns without smoke and with little flame. It is used in America for a great variety of purposes. The annual consumption in 1821 was 2000 tons. There are two beds of coal: the uppermost varies in thickness from 12 to 18 feet, the lowest is 14 feet thick; the other beds are sandstone, slate clay and shale. The vegetable impressions are numerous, and, as far as can be judged from the imperfect account of Mr. Cist, they resemble those which occur in our own coal beds. All these vegetable impressions are in the slate clay above the coal; very few, if any, fossils have been observed under the coal.

14. A coal field occurs in the county of Chesterfield, in Virginia, just on the south side of James' river, and about a hundred miles west from the Atlantic Ocean. From Mr. Grammer's account of these mines* the country appears to be primitive, and the coal metals are considered as deposited directly over the granite, though the contact of the two has not been observed. Only one bed of coal has been worked the thickness of which varies from thirty to fifty feet. The coal is similar to our own slate coal. This bed has been burning for a great many years. The combustion goes on very slowly. Various attempts have been made to put out the fire by letting water into the pit, but they have not been attended with success. Advantage has been taken of this combustion to ventilate the mines; a level has been cut to an old abandoned pit in the vicinity of the burning part of the bed; a door is put on this adit; when the miners begin to be incommoded with foul air this door is opened, a rapid motion of the air immediately takes place towards the burning part of the bed, which cleans the pit of foul air.

15. In Nova Scotia, not far from the upper extremity o the bay of Fundy, and particularly round what is called *Mines basin*, coal fields have been discovered in fourteen differen places. The most extensive coal tract is in the district o Pictou, near Northumberland straits, which separate Nova Scotia from the island of St. John, near a place called New

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* Silliman's Jour. vol. i.

Glasgow. Six or eight shafts have been sunk by Mr. Carr and excellent coal found, which is now exported in considerable quantities to the United States.

From the Geological Account of Nova Scotia, published in the *Memoirs of the American Academy*, by Messrs. Jackson and Alger, it appears that the country in which these coal metals occur is granite. No accurate description is given; but from the map, which they have published, it would appear that the basins filled by the coal beds are hollows in the granite. The granite is succeeded in that country by a clay slate, to which Messrs. Jackson and Alger (it does not appear for what reason) have given the name of *transition slate.**

16. But the great coal country of North America is the immense basin of the Missouri, interposed between the Rocky Mountains on the west and the Alleghany mountains on the east, constituting a prodigious tract of fertile country not less than 1500 miles square. Mr. Maclure conjectures that the whole of this region was once a lake or inland sea, which was drained by the river St. Lawrence forcing its way to the Atlantic Ocean on the east and the Mississippi on the south. Immense tracts of coal occur in this basin, some of which, it is said, have been already worked; but they cannot come into general use till the country be sufficiently peopled and denuded of wood, to occasion a demand for that kind of fuel. There cannot be a doubt that this vast and fertile basin, so richly furnished with fuel and with soil, is destined one day to become one of the most powerful and flourishing countries in the world.

17. We know very little about the coal formations in South America, though it is well understood that various such exist. Humboldt mentions a coal field on the table land of Sta. Fe de Bagota, at the height nearly of 8,700 feet above the level of the sea. He informs us that coal beds exist also in the high Cordilleras of Huarocheri and of Contu. It is even said that

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* According to these gentlemen, a Geological Account, by whom, of Nova Scotia has been inserted in the *Memoirs of the American Academy,* for 1832, this country is composed chiefly of transition slate. The country contiguous to the sea is alluvial, except at Halifax, where the clay slate rocks come to the shore. Behind the alluvial deposits is a broad zone of transition slate, extending from near Cape Breton to St. Mary's bay on the west. A narrow zone along the Annapolis river is quartz rock; this is succeeded by a narrow zone of red sandstone, dipping under the trap rocks which surround the bay of Fundy.

they occur near Huanuco, mixed with magnesian limestone, very near the limit of perpetual snow, or at the height of 14,700 feet above the level of the sea. There are numerous coal tracts in New Mexico, in the central parts of the saline plains of Moqui and Nabajoa, and likewise near the sources of the Rio Sabina.

From the preceding history of the coal formations in different parts of the world, imperfect as it is, we see that the coal measures are sometimes mixed with the lias beds, sometimes with the magnesian limestone; sometimes they repose on millstone grit, sometimes on mountain limestone, sometimes on old red sandstone or greywacke, sometimes upon clay slate and sometimes upon granite. The coal in the *lias* is doubtless of a posterior date to that which lies below the magnesian limestone. But the era of the magnesian limestone and of the coal measures, though posterior, is not, perhaps, very different. The reason of the difference of the position of the other coal beds, with respect to the lower strata, must be the occasional absence of certain beds.

CHAP. XIII.

GREYWACKE AND OLD RED SANDSTONE FORMATION.

The term *transition* was applied by Werner to certai rocks, because he was of opinion that they were deposite when the earth was passing from an uninhabited to an inhabited state. The evidence of this opinion was, that the contained the fossil remains of vegetables and animals, whil no such remains occur in any of the rocks situated below them Werner affirmed that the fossil remains in the transition rock belong exclusively to the lowest classes, both of the vegetabl and animal kingdom. It is now known that these opinion were ill-founded; it can be proved that the earth was inhabited at least, by fishes and plants before the transition rocks wer deposited; and surely it would be too much to affirm tha fishes and filices and equiseta belong to the very lowest classe of animals and vegetables.

The only one of the transition rocks of Werner which seem capable of coming under a general arrangement is the on which he distinguished by the name of *greywacke*. This roc alternates very frequently with a clay slate, which, on that account, has received the name of *transition* or *greywacke slate*, though it is impossible, in many cases, except from position, to distinguish between *primary* and *transition clay slate.* Large masses of limestone occur in the greywacke, or interposed transition slate. This limestone frequently constitutes whole mountains; from its situation it is known by the name of *transition limestone.* The greywacke is a sandstone the fragments of which are cemented together by clay slate; but sometimes it puts on the appearance of a conglomerate, and not unfrequently the grains become so fine that it assumes the form of a sandstone. Its colour in that case being usually *red* (though sometimes purple), it has been distinguished by the name of *old red sandstone.* As this sandstone cannot be distinguished from *new red sandstone* or *coal sandstone,* except by position, these three sandstones have frequently been mistaken for each other; this has introduced considerable confusion into the subject, which can only be cleared up by a greater attention to the position of the rocks submitted to description, or by attending carefully to their fossils, when they contain any.

The term *greywacke* (in German *grau wacke,*) was given by the Saxon miners to a rock near Freyberg, remarkable for the many metalliferous veins which it contains. It is a sandstone, composed of fragments of quartz, felspar, lydian stone and clay slate, often exceedingly hard, or much more siliceous than common. Or we may define it a siliceous clay slate containing numerous fragments of quartz, felspar, lydian stone and clay slate. The imbedded masses vary in size, but seldom exceed a few inches. When they are very small the sandstone appearance of the rock vanishes, it assumes a slaty structure and is then known by the name of greywacke slate or transition slate. Greywacke is termed by the French *traumate* and *psammite.*

Greywacke, like other sandstones, is stratified, and the stratification can be still better seen by its alternating with clay slate. Now, the remarkable circumstance is, that these beds (so far as I have seen) are never horizontal, but almost always very nearly perpendicular. It is clear from this that they have been exposed to some violent action since their original deposition, and this is partly accounted for by the fact that they are always, or at least generally, more or less mixed with trap rocks, to which, doubtless, they owe their position.

There is a range of transition mountains in Scotland which begins at St. Abb's Head, the southern termination of the Frith of Forth, and extends with little interruption till it terminates in the Irish sea, on the north side of Loch Ryan in Galloway. This range extends in length about one hundred and twenty miles, and includes the mountains of Galloway, Dumfries, Lanark, Peebles, Mid Lothian, and Berwick. The highest part o the tract is near Moffat, where Hartfell rises to the height o 3300 feet above the level of the sea. Lowther, near Leadhills, which is in the same range, is 3130 feet high. Thi mountainous tract is composed of transition rocks; but from the abundance of greenstone found in it, the whole has bee thrown into such inextricable confusion, that it would be difficult task to determine the relative position of each rock The kind of rocks found in the range, so far as I hav observed, are greenstone, clay stone, porphyry, greywacke clay slate, alum slate, and sandstone. The sandstone constitutes the principal part of some of the Pentlands west fro Edinburgh, and I think it probable, from the situation, tha this sandstone belongs to the coal beds, though this is merel a conjecture.

About five miles south of Edinburgh, in the Pentlands which constitute a part of this chain, there occurs a romanti valley, and Mr. Playfair, who used to visit it occasionally distinguished it by the name of the *Valley of the Pentlands* It was formerly a favourite resort of the inhabitants of Edinburgh during the summer months, being marked by traditio as the *Habby's Howe*, which constitutes the site of Allan Ramsay's *Gentle Shepherd*. The lower part of this valley is composed of alternate strata of greywacke and clay slate. Th soil has been removed on the north side, and the rock lai bare, by the action of a rivulet for about 100 yards. Th beds are in general thin, sometimes only a few inches. Thes beds are standing almost perpendicular to the horizon. have observed the same beds in nearly the same position t the east of Soutra Hill, one of the Lammermuir chain, whic terminates at St. Abb's Head, and indeed in various othe spots of the hilly part of Berwickshire. Indeed, if we traverse the country from the Tweed to the Lammermuirs, w will find the red sandstone, which at the Tweed distinctl covers the coal measures, gradually and insensibly passing int greywacke. The same greywacke rocks are visible at Moffat where they have been used as a building stone; but I had no an opportunity of determining the relative position of the beds

Good sections of greywacke may be also seen in the mountains north from Loch Ryan. The road from Glasgow to Port Patrick crosses these mountains. It is steep and inconvenient for the traveller, but admirably contrived to furnish the geologist with sections of transition rocks. The hill behind General Wallace's house, at Carn, is composed of clay slate, and this slate alternating with greywacke, may be traced for several miles north, till the mountainous country suddenly terminates a little to the south of Girvan.

The greywacke slate which lies over the granite and gneiss district at Loch Ken, in Galloway, is probably a continuation of, or at least connected with the great transition tract just mentioned.

There is another extensive transition series of rocks in Cumberland, which have been gradually investigated by Otley, Phillips, and Professor Sedgwick. It constitutes the country round the lakes, so frequently visited on account of the romantic nature of the scenery.

The undermost portion of this tract consists of primary rocks. The lowest bed of all is granite. Skiddaw, and the neighbouring region, consist of gneiss and hornblende slate, over which lies a formation of clay slate which is considered to be transition slate. Over this lies an enormous formation of green slate, intimately associated with a porphyry very similar to that which constitutes the summit of Ben Nevis.

Next comes the greywacke system of rocks, containing calcareous beds with organic remains. Towards the south side of a line drawn from Skiddaw to Egremont, there is a group of mountains composed almost entirely of diallage rock. It is in precisely the same position with the rocks of the district as a similar rock in the peninsula of the Lizard, Cornwall.

The greatest part of North Wales consists of transition beds. These beds consist chiefly of three sorts of rocks: 1. An extensive porphyry district. 2. Clay slate, exceedingly abundant, and often capable of being split into very thin roofing slates. The greatest part of England is supplied with slate from Wales, which forms a lighter roof, but not so durable as the Scottish slate. 3. Greywacke containing in its upper part organic remains, and gradually passing into slate.

There is a variety of slate at Snowdon, seemingly approaching very closely to the slate in the Cotentin, which Brongniart has distinguished by the name of *steashist.*

In the neighbourhood of Plymouth, alternations of clay slate occur with limestone containing conchiferous and coralline fossils, and therefore considered as transition limestone. The clay slate possesses all the characters of primary slate, except that it alternates with the transition limestone. No greywacke rocks can be discovered in the neighbourhood of Plymouth. But a little to the east of Truro, there was, about twenty years ago, a greywacke quarry near the road, the stone from which was employed in mending the roads. The clay slate, unchanged in its characters, continues to form the fundamental rock of Cornwall through the greater part of the county. In the peninsula of the Lizard it is interrupted by a deposit of greenstone, connected with which is a formation of diallage rock and serpentine, all of which, have doubtless been forced up from below. The granite rocks which run from the Landsend to Dartmoor, with certain interruptions on the surface, though probably united below, are most likely to be referred to a similar cause.

The Plymouth limestone rises into low hills near the sea-shore, and was employed in constructing the breakwater. It is a variegated compact limestone with a splintery fracture, most commonly reddish or blackish, and capable of taking a good polish, and is a variety of what is well known under the name of *Devonshire marble.* Shells and corallines are by no means uncommon in this limestone.

There is a *conglomerate rock* which occurs at Oban in Argyleshire, which has so many relations to greywacke, though I was unable to find in it any fossil remains, that I think its formation must be referred to the same period. The fundamental rock of the country is primary clay slate, over which the conglomerate lies in an unconformable position. It must therefore have been deposited and solidified after the clay slate and after the deposition of all the primary rocks in that country; because it is composed of fragments of these rocks.

This conglomerate makes its appearance about five miles to the north of Oban, constituting a range of low hills that run east and west a little to the north of the Connal Ferry over Loch Crerar. The little hill called Berigonium, considered as a vitrified fort, and fabled to have been the capital of Caledonia, is composed of this conglomerate. The low islands at the mouth of Loch Crerar consist of the same conglomerate. They serve to connect these hills with the one on which Dunstaffnage Castle is built, which is also composed of conglomerate. The rock continues along the sea shore to Donolly Castle, which is likewise built on a conglomerate rock, so steep on all sides but one, that Donolly must have been a place of great strength in olden times. About a furlong north of Donolly the upper part of the cliff retires back a good way from the sea, leaving a space not unlike the undercliff in the Isle of Wight. The rocks on the beach are still conglomerate above, but below they assume the form of a hard, purplish, slaty sandstone, intermixed with water-worn pebbles. This sandstone is stratified, the beds varying in thickness from an inch to some feet. It dips east below the conglomerate at a small angle, the dip not exceeding 1 foot in 24.

In like manner at Oban, where there is a beautiful bay constituting the harbour, the conglomerate rocks retire backwards, and form the high bank which protects the village on the east. This part of the rock is covered with grass, except at the south end, where a fine section presents itself to the view of the geologist.

The conglomerate continues along the sea shore to the ferry of Kerrera, about a mile and a half distant, where its continuity is interrupted by a broad basalt dyke. It may be followed four miles farther south, where it may be seen lying over the clay slate beds. How much farther south it proceeds I do not know, the encroachments of the sea rendering it inconvenient to proceed farther except in a boat.

The same conglomerate makes its appearance in the Island of Kerrera, situated to the west of Oban, about half a mile or three quarters of a mile from the main land, and thereby constituting a secure and spacious natural harbour. We can trace the rock from the north end of the island to the ferry, which is nearly half way between its two extremities. The south end of the island consists chiefly of clay slate.

How far inland these conglomerate rocks extend cannot easily be determined, the nature of the country presenting almost insurmountable obstacles to such an examination.

This conglomerate consists of a congeries of water-worn and rounded pebbles of very various sizes, united very firmly without any visible cement. Some are not larger than a grain of sand, while others constitute spherical or ellipsoidal masses 7 feet in length, and 5 feet in breadth and thickness. The most common size is from that of a human head to that of the two fists. These pebbles are all fragments of the primary rocks in the neighbourhood; granite, clay slate, felspar, quartz are common, but the most abundant constituent is the felspar porphyry, which constitutes the summit of Ben Nevis, which exists in Glenco, and in many other parts of the neighbourhood. These pebbles bear such characteristic marks of their original, that there can be no doubt about it. For example, there is a variety of clay slate conspicuous on the sea shore near Kerrera ferry. It is of a very dark blue colour, almost black, and full of quartz veins. At first sight it looks like basanite, though the slaty texture of the rock when viewed in situ leaves no doubt about its nature. Now this variety of clay slate is a common ingredient in the conglomerate rock.

The conglomerate rock in the island of Kerrera, immediately on the south side of the ferry, differs in its appearance from that on the main land. It consists chiefly of fragments of clay slate and mica; and these, though water-worn, are not rounded, but remain flat with rounded edges.

No appearance of stratification can be seen in the upper part of this conglomerate rock; but the lower portion is divided into regular beds, and consists of a soft sandstone, with interspersed water-worn pebbles, which, however, are few in number, compared with the sandstone in which they occur. This soft sandstone does not pass gradually into the conglomerate: the line of demarcation is quite distinct.

The dip of the conglomerate is variable, but every where it is to the north-east; while the dip of the clay slate on which it lies is south.

With respect to the origin of this conglomerate there can be no doubt. The primary rocks in the neighbourhood must have been fractured, and the fragments washed down into the sea by the violent action of water. They must have been long exposed to the action of the waves of the sea, since the pebbles are all rounded. After this process they must have been agglutinated together, and finally raised above the level of the sea to their present position.

How the agglutination was produced we may have some conception if we attend to the circumstance, that this conglomerate is every where intersected by trap dykes, which usually have a direction from south-west to north-east. These trap dykes doubtless made their way through the conglomerate while in a state of igneous fusion. Now this heat may have been so intense as to have softened the superficies of the pebbles, of which the conglomerate is composed, and thus have caused them to cohere together; for although no cement can any where be seen uniting the constituents together, yet the adhesion is so strong that it is often easier to fracture a pebble than to separate two pebbles from each other.

The probability is, that the consolidation took place under the sea, and that the elevation of the conglomerate was a subsequent, and probably a gradual process. The west coast of Lorn, from Dunstaffnage to Gallochin, an extent of about eight miles, bears unequivocal marks of having been elevated at no very remote period. A considerable portion of this coast consists of pretty steep rocks, the summits of which are elevated 300 or 400 feet above the level of the sea. Now these rocks show clearly that they have at no very remote period been washed by the sea at a height certainly more than 30 feet above the present high-water mark. Now, as we cannot suppose the sea to have subsided 30 feet in this place without producing a corresponding change upon the other parts of the coast, we have no other alternative but to admit that the conglomerate has been elevated at least to that amount; and if we admit an elevation of 30 feet, there can be no reason for refusing our assent to an elevation of 300 or 400 feet subsequent to the period of the consolidation of the conglomerate.

Thus the conglomerate of the coast of Lorn resembles greywacke, in being composed of the debris of primary rocks. We are able even to form some notions of the way in which it has been formed, consolidated, and elevated; nor can there be any good reason for refusing to apply the same principles to the formation and subsequent elevation of greywacke itself.

Parallel to the south-east flank of the Grampian mountains, here runs a chain of low hills. These hills are very irregular n their position, and are separated from each other, and from he Grampians, by intervening valleys, sometimes constituting plains of considerable extent. I have had an opportunity of xamining these hills only at the west end of Strathearn. From the village of Crieff, which is situated upon the side of ne of these hills, when we turn our eyes around, we see urselves surrounded, on the south-west and north, by an mphitheatre of little hills, which, varying each in size and n shape, and being covered to the summits with wood, while he prospect is closed on the west by the Grampians, constitute one of the most lovely landscapes any where to be seen. The Earn and the Turret may be observed making their way between these fantastic little hills, and, after uniting their streams in the plain, making their way together through the extensive valley of Strathearn, till the view is closed by the distant hills beyond Perth.

These hills are composed of greywacke, which assumes various appearances in different places. Sometimes it has very nearly the appearance of common greywacke rock. Sometimes it is a very coarse red conglomerate, composed chiefly of a porphyry very like that of the rocks at Glenco. Sometimes it is a pretty fine-grained red sandstone, composed chiefly of grains of quartz; and the strata, which are very distinct, are nearly vertical. The cement of this sandstone is sometimes clay, sometimes clay slate. The grains are very fine, and it contains much mica. A similar stone occurs in Strathearn; but as it is deposited in strata perfectly horizontal, while those in the hilly tract are vertical, I am disposed to consider the sandstone of the flat country as belonging to the new sandstone series.

Dykes of greenstone occur here and there in this greywacke district. There is one at Monzie, on the south flank of one of these old red sandstone hills, which is extensively quarried for mending the roads.

The old red sandstone beds, described by Buckland and Conybeare, as lying under the south Gloucester and Somerset coal beds; and also the same rock lying under the South Welsh great coal formation, probably belong to the same formation as the red sandstone in Perthshire, or, more accurately speaking, skirting the Grampians on the south-east flank. For I have noticed the existence of similar deposits in the same situation, in Stirlingshire and Dumbartonshire.

The origin of the greywacke and old red sandstone, is obviously to be ascribed to the destruction of the older rocks; and doubtless the clay slate which is interposed between the beds of greywacke, and which, in fact, greatly exceeds it in quantity, owes its origin to the same cause, and consists of the debris of those rocks reduced by the action of water to an impalpable powder; which, after its deposition in regular strata, had been subsequently consolidated by pressure, heat, or some other unknown cause. But the origin of the transition limestone is not so easily explained. If we compare with each other the quantity of limestone which exists in the different formations, we shall find that it increases pretty regularly, according as the formations become newer. There is least of all in the primary formations, more in the greywacke series,

; in the coal beds; still more in the new red sandstone ıore still in the oolite, and most of all in the chalk.]uence of this regular increase, and on account of the ıs number of the remains of shells and corals which hese limestones, it has been supposed that these lime-ds owe the greatest part of their contents to the ıf testaceous animals and polypifers. This explana-'ever, can apply worst of all to the transition lime-cause it contains much fewer fossils than those which he subsequent beds.

ossil remains in the greywacke group are pretty ;. The fullest catalogue of them which I have seen by De la Beche.* He enumerates 378 species, the trilobites, and the remains of fish, which, in have not been attempted to be classified; of these, s belong to plants, 77 to zoophyta, 34 to radiaria, 4 ıta, 201 are shells, and 48 crustacea.

ılants, employing the generic names of Brongniart,

, 3 species,
s, 3 species,
teris dissecta,
ris flabellata,
is aspera,
13 species.
Sigillaria tesselata, Voltzii,
Lepidodendron,
Stigmaria ficoides,
Asterophyllites pygmæa.

oophyta include the following genera:—

ı,
ıpera,
ıra,
a,
ı,
'a,
Agaracia,
Lithodendron,
Caryophyllia,
Anthophyllum,
Turbinolia,
Cyathophyllum,
Strombodes,
Astrea,
Columnaria,
Coscinopera,
Catenipora,
Syringopora,
Tubipora,
Calamopora,
Aulopora,
Favosites,
Mastrema,
Amplexus.

nost abundant genera of shells are terebratula, pro-ecten, cardium, patella, orthoceratites. The most t genera of the crustacea are Calymene, Asaphus, tes, &c.

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* Geological Manual, p. 455.

From the various forms of the fossils imbedded in the greywacke, we may infer, that the animals of which they constituted the solid parts, occupied situations as different as those of the present day: some preferring deep waters, while others were fitted for shallow waters; and not a few must have swam freely in the open ocean. The orthoceratites are found of a large size, a yard or more in length. If, therefore, they constituted a part of a swimming molusca, like the nautilus their size must have greatly exceeded that of any similar animal at present known to exist. Productæ are common to the greywacke, coal, and new red sandstone group. Spinifer have been observed as high up as the lias; but they are much more abundant in the greywacke. The terebratulæ are much more copiously distributed through the mineral kingdom; fo they exist in all the formations, from the greywacke to the very newest; and many species exist alive in the ocean at the present day. I need not observe that many of the greywacke fossils, especially the zoophyta and conchifera, exist in the transition limestone. Mr. Hennah has given a valuable account of those found in the Plymouth limestone. He found in it various species of zoophyta, belonging to the following genera:—

Polyparia,
Stylina,
Caryophyllia,
Turbinolia,
Crinoidea.

Besides a considerable number of shells.

The family of trilobites must have abounded in particula places during the deposition of the greywacke. In some parts of Wales the *Asophus Debuchii* is so abundant that the laminæ of the slates are charged with them, so that millions may be met with within a limited space. The trilobite long known under the name of the *Dudley fossil*, because so common in the neighbourhood of that town, is the *Calymene Blumenbachii* of Brongniart. The trilobite family is now entirely extinct, and it seems to have disappeared before the productæ. No traces of them have been discovered in the *lias*, nor *new red sandstone*, nor even in the *coal beds.*

Among the corals are found several genera now existing It deserves notice that wherever there is an accumulation of polypifers in the fossiliferous rocks, such as would justify the accumulation of coral banks or reefs, the genera Astrea and Caryophyllia are present; genera which, according to the more recent observations of naturalists, are, joined with a few others, the principal architects of coral reefs at the present day.*

The fossil vegetables found in the greywacke beds are similar, though far less abundant, to those found in the coal measures.

Mr. Weaver has shown that greywacke is an abundant formation in the south of Ireland. It is found also abundantly in France and in Germany; though it would be inconsistent with the extent of this work to enter into a detail of the localities. But the transition rocks in Sweden are so peculiar in their situation that a short account of them ought not to be omitted.

In West Gothland constituting an extensive district in Sweden to the west of the lake Wenner, the country is flat, with twelve little hills rising insulated through it. The highest of these, Kinnekulle, is only 920 feet above the level of the lake Wenner. The province consists of beds of gneiss, alternating with granite, and stratified often almost horizontally. So much so that the country east of Trollhätta for an extent of eight or ten miles has exactly the appearance that it would have had if it had been artificially covered with flagstones. The twelve little hills consist of transition rocks seemingly reposing on the gneiss.

Kinnekulle for instance consists of five beds lying over each other in nearly a horizontal position. The lowest of these is a sandstone, doubtless a variety of greywacke. Over this is a thin bed of alum slate, from which an alum manufactory in the neighbourhood in 1812 was supplied with ore. This slate contains nodules of stinkstein, and contains fossil remains. The third bed is a compact limestone abounding in petrifactions, the most common of which are orthaceratites and echini. Over the limestone lies a bed of slate clay. The uppermost and smallest bed, constituting the conical summit of the hill, is a fine grained greenstone. It has probably made its way from below, and has acted as the consolidating agent of the other beds.

There are two little hills which lie at the southern extremity of the lake Wenner, and about a mile east from Wennersborg. These are called Halleberg and Hanneberg. The latter is southernmost, and is separated from the former by a

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* See De la Beche's Manual, p. 470.

narrow valley. The height of these hills does not much exceed 200 feet, but they are so steep on every side that it is no easy matter to ascend them. The summit is nearly flat, so that they constitute a table-land about seven miles in length, and nearly as much in breadth. These hills are composed of the following beds, beginning with the lowest which reposes on the gneiss, of which the flat country is composed:—

1. A white sandstone composed of rounded quartz grains.
2. Iron shot clay mixed with pyrites.
3. Alum slate, black, and much mixed with pyrites.
4. Fibrous limestone containing petrifactions.
5. Alum slate with nodules of stinkstein as at Kinnekulle.
6. A very fine grained greenstone constituting three-fourths of the hill and crowning it.

In these hills the sandstone is the substitute for greywacke or old red sandstone, and the alum slate for the clay slate which usually alternates with that rock. The structure of the remaining nine little hills is similar. The reason why the sandstone constituting the base of these hills is so different in its appearance from greywacke seems to be this: From the constituents of greywacke it is evident that it is composed of the debris of the rocks on which it rests. And these rocks in this country and in Germany where greywacke abounds, are chiefly clay slate. But clay slate being altogether wanting in Scandinavia, the sandstone formed from the disintegratio of gneiss (the fundamental rock in Scandinavia) could no possibly resemble greywacke, which consists chiefly of th debris of clay slate.

When greywacke lies immediately contiguous to primar rocks it sometimes seems to alternate with them. Thus D M'Culloch describes greywacke and quartz rock as alterna ing in the gneiss beds which constitute the eastern portion the Isle of Skye. Such appearances are doubtless owing alterations produced in the relative situation of rocks by th agents to which these rocks were indebted for their conso dation.

CHAP. XIV.

STRATIFIED PRIMARY FORMATIONS.

The greywacke group is the lowest series of beds that contain petrifactions. Those which lie below them (with a few trifling exceptions) are entirely destitute of the remains of animals or vegetables. On that account they have been usually denominated *primary* or *primitive* formations, indicating by the term that they are still in the same state as when they came from the hands of the Creator. But as a considerable number of these formations are in beds deposited regularly above each other, we have the same evidence that they were formed under the surface of the sea, that we have for the similar deposition of the secondary strata. The absence of fossil remains undoubtedly constitutes an important distinction between primary and secondary rocks, but it does not destroy the evidence derived from stratification. It may be that the unfossiliferous stratified rocks were deposited and solidified before the earth was inhabited by animals or vegetables. Or, as is more likely, they may have contained fossils at the time of their deposition, but all remains of them may have been obliterated by the agent by means of which they were consolidated.

The relative position of the stratified unfossiliferous formations is not quite uniform, but in general they occur in the following order, beginning with the uppermost rock:—

1. Clay slate.
2. Mica slate.
3. Gneiss.

Beds of hornblende slate, chlorite slate, quartz, and granular limestone, occasionally occur interspersed through the three preceding rocks, and these sometimes become so considerable as to constitute whole mountains.

1. *Clay Slate.*

Clay slate, the uppermost of the unfossiliferous stratified formations, is a rock well known in this country, being the substance commonly used for roofing houses.

The colour of clay slate is very various, grey, blue, red, yellow, but by far the commonest colour is blue of various shades.

Its texture, as the name implies, is *slaty*, and there is great difference in the degree of thinness into which thes slates can be split. The texture of the rock then is slaty, an sometimes the foliæ are straight, sometimes curved. It i only in the former case that the rock answers for makin roofing slates. Very often the slates in the rock alternat with quartz, and constitute a rock slaty to the eye, but incap able of being split, because the clay slate and the quar cohere very firmly. Indeed, in such cases the slaty portio of the rock is so thin, that if it could be separated from t quartz it would not be of any service as a roofing material.

The lustre of clay slate is more or less pearly, or at lea silky.

Its specific gravity is about 2·7.

Its constituents, determined by analysis in my laborator are as follows:—

Silica,	49·232	59·11
Alumina,	14·560	19·41
Lime,	5·540	1·12
Protoxide of iron,	20·776	11·45
Magnesia,	2·248	4·51
Soda,	—	—
Moisture and volatile matter,	8·200	4·35
	100·556*	99·95†

Clay slate almost always contains cubic crystals of i pyrites interspersed through it. These have a yellow colo the metallic lustre and a considerable degree of hardn When clay slate alternates with greywacke it contains ab dance of petrifactions, and is known by the name of *transit slate*. Pyrites is much less common in transition clay sl than in what is called primary slate.

Beds of granular limestone, of chlorite slate, and of qua are common in clay slate mountains.

Clay slate usually occurs in mountainous districts, seld in plains. The mountains composed of it are someti round backed, but they much more frequently rise into sh cliffs, sometimes quite precipitous on one side to a very c siderable depth. Ben Lomond, which is rather an eleg shaped mountain, is composed of clay slate, and from

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[*] A green coloured slate from Ireland. Specific gravity 2·531.

[†] A bluish grey slate, with darker spots, from Germany. Specific gra 2·761.

summit on the north-east side there is a perpendicular cliff that cannot be under 1000 feet high.

A considerable portion of the Grampian mountains in Scotland is composed of clay slate. For example, Glen Almond, a romantic ravine through these mountains, through which the road passes from Crieff to Kenmore, exhibits on both sides a majestic section of clay slate mountains. The same remark applies to Glen Queach, which may be considered as a continuation of Glen Almond. The mountain to the south of Kenmore is composed of clay slate. About four miles west of Kenmore, on the north bank of Loch Tay, mica slate rocks make their appearance, and Ben Lawers is composed of mica slate. But as we approach Killin, at the west end of Loch Tay, clay slate rocks again make their appearance. From this section of the Grampians to the extremity of the Mull of Kintyre, where the range may be said finally to terminate, a distance of about one hundred and twenty miles, and more than half the length of the Grampians, they consist almost entirely of clay slate. Clay slate beds may be seen also on the north side of the Grampians, in Aberdeenshire, and on its south side, in Kincardineshire. Hence it probably extends along the whole course of these mountains.

It has been already observed, that the clay slate in Wales contains abundance of fossils, particularly the *Asaphus Debuchii.* On that account, and because it alternates with greywacke, it is considered as *transition slate.*

The clay slate in the neighbourhood of Plymouth alternates with the limestone of that neighbourhood, which contains fossil remains. On that account it is considered also as transition slate. Now this clay slate is continued with little interval from Plymouth through the whole of Cornwall, and no good reason can be assigned for considering the age of the Cornish *killas* (the name in that county for *slate*) as different from that of Plymouth. This clay slate in general contains no fossils, yet they have been met with in the clay slate of Tintagel in Cornwall. Perhaps therefore there is no very valid reason for considering the age of the *primary* clay slate as very different from that of the transition. The shells from Tintagel are figured in the *Geological Transactions*, iv. 25. Those from Snowdon are figured in the *Annals of Philosophy* (second series), iv. pl. 17.

Clay slate rocks occur on the coast of France opposite to

Cornwall, in Britanny, mixed with granite, and also with greywacke; and Brongniart has given it as his opinion that these beds are fossiliferous; but I am not aware that this opinion has been verified by the discovery of any fossil remains in them.

2. *Mica Slate.*

When a mountain mass is granitic, it was the opinion of Werner that the central and highest portion of it consisted of granite; that this central portion was enveloped on all sides in beds of gneiss wrapt round it mantlewise, and that these beds thinned out and disappeared before we reached the upper part of the mountain. Still lower down, beds of mica slate were wrapt round the gneiss as it had been about the granite, and thinned out and disappeared before they reached the height of the summit of the gneiss beds. Still lower down clay slate beds wrapt round the mica slate beds, and thinned out in their turn before they reached the upper summit of the mica slate. Though this description is certainly very far from holding good in all cases, yet it must be admitted that an approximation to it may be frequently observed. Thus in the southern part of Aberdeenshire the central portion of the Grampians consists of granite. Whether this granite central mass be wrapt round by gneiss I do not know from personal inspection, but have been told that it is. Mica slate rocks may be seen both to the north and the south of the granite chain. The beds of these rocks are very much elevated, and they obviously lean against the granite central mass just as would have happened had the mica slate been originally deposited in horizontal beds, and the granite had forced its way upwards through these beds in a state of fusion.

Mica slate is a stratified rock composed of mica crystallized in plates, and quartz. The mica being usually in thin leaves is much more bulky than the quartz, which it frequently conceals so effectually that its presence can only be recognised by breaking the mineral into small fragments. Sometimes, indeed, the quantity of quartz is so small that in hand specimens it cannot be recognised. In such cases the grains o mica become very small; it begins to assume the silky lustr of clay slate, and gradually passes into that rock. So that i a congeries of beds consisting partly of mica slate and partl of clay slate, it is difficult to determine where the one roc terminates and the other begins.

Crystals of *garnet* (the variety called *precious garnet*) are almost always interspersed through mica slate, often in great numbers and of all sizes. They of course serve to characterize this rock. In clay slate they are very rare, and though they occur in gneiss yet they are uncommon in that formation.

In the Grampians the mica slate rocks begin about Ben Lawers, which is composed of it, and it seems to proceed with little interruption from that place to the south-eastern extremity of the range.

Mica slate contains in it a considerable number of subordinate beds. The most common of these is *chlorite slate*, which occurs near Inverary, in Argyleshire, where the rocks are composed of mica slate. The Duke of Argyle's house at Inverary is built of chlorite slate, from quarries in the neighbourhood.

Dolomite, or magnesian limestone, containing crystals of tremolite, epidote, tourmaline, lepidolite, amphibole, corundum and magnetic iron ore, is said to constitute a bed in mica slate in the Alps, but this is doubtful; for many of the localities in the Alps, which Brochant described as composed of transition or primary rocks, have been since ascertained to be of much later origin, and to belong to the new red sandstone, the oolite, or even the chalk series.

Beds of quartz rock, usually white, with thin plates of mica interspersed through it, are rather common in the mica slate, as well as in the clay slate formation; such beds are frequent in our Grampians. Hornblende and hornblende slate occur also in beds, both in clay slate and mica slate mountains; such beds are abundant in the Grampians. In the pass of Larikeely, between Loch Earn Head and Killin, an enormous bed of this kind may be seen cut through by the road. The country is composed of clay slate.

Emeralds occur usually in mica slate, though those at Muzo, in New Grenada, are found, according to Humboldt, in a bed of hornblende slate, which, however, is subordinate to mica slate; syenite also occurs in mica slate. This at least is the case in the Shetland islands, a portion of which is composed of mica slate. We have an interesting geological account of these islands by Dr. Hibbert, in the first and second volumes of the *Edinburgh Philosophical Journal.* They consist entirely of primary rocks, and are composed chiefly of granite and gneiss; but beds also of mica slate are met with, remarkable for the syenite which they contain. There appears a striking analogy between the structure of the Shetlands and Sweden; while the Orkneys, which consist chiefly of new red sandstone, are geologically connected with Caithness, which consists partly of new red sandstone and partly of lias.

In Europe mica slate constitutes a very extensive and wide spreading formation. In America it is less common; and in that country, according to Humboldt, it never contains beds of porphyry, nor does it pass into porphyry; while, according to Von Buch, this happens in the Splügen Alps, between the village of Splügen and the valley of Schams.

Humboldt informs us that mica slate is almost wanting in the Cordilleras of Mexico and South America. The primary rocks in these districts, he says, consist of alternate beds of granite and gneiss mixed with syenite.

3. *Gneiss.*

The unfossiliferous stratified rock, which commonly lies contiguous to granite, when the two formations occur together is *gneiss*. Now gneiss is a schistose rock, composed of *felspar*, *quartz* and *mica*. These constituents are deposited in alternate layers. Hence the slaty structure so conspicuous in this rock, from the difference in the colour of the felspar and mica, which generally enter most abundantly into the composition of gneiss. In the gneiss rocks most approaching to the granite in situation, or what is usually called the *oldest gneiss*, the quantity of mica is comparatively small, the rock being chiefly composed of felspar; but it increases very much as we approach the mica slate rocks, and becomes at last so abundant, that we can scarcely distinguish it from this last rock, into which it gradually passes.

The word gneiss *(gneuss)* is German, and was given by the Freyberg miners to the rock in which most of the mineral veins of Saxony occur. When this rock was constituted by Werner into a particular formation, he naturally adopted the name by which it had been already distinguished. In this way it made its way into geology, and has long been current in all European languages.

It is but rare to find gneiss for any great space quite pure; it almost always alternates with other rocks, and the most common of these is *granite*. The greatest part of the vast peninsula of Scandinavia consists of gneiss, in this way alternating with granite. In the Scandinavian gneiss, mica is very little abundant; it consists chiefly of felspar and quartz, though to this there are many exceptions. When it loses the slaty fracture, and becomes granular, then it cannot be distinguished from granite, into which, of course, it passes. Adam's peak, a celebrated mountain in Ceylon, between 6000 and 7000 feet above the level of the sea, is composed of gneiss, as we are informed by Dr. Davy.

Gneiss rocks were thought to be richer in gold and silver ores than any other formation. The gneiss of Germany, of France, of Greece and of Asia Minor yields silver, for the silver mines worked by the ancients in the two last countries, and so much celebrated for their riches, were situated in gneiss. It is now known, however, that the greatest silver mines are situated in newer rocks. This is the case with the Mexican mines, which supply more silver than all the rest of the globe put together.

The only part of Great Britain where gneiss rocks occur in any quantity, is the granite tract which runs along the Dee, in Aberdeenshire. On both sides of that tract gneiss rocks recline against and cover the sides of the granite. There is also a tract of gneiss which begins at the Coran ferry, nine miles south of Fort William, in Inverness-shire. The range of mountains constituting the north side of Glen Tarbert, which runs in a westerly direction from the Coran ferry to Strontian, in Argyleshire, are gneiss. The range would appear to terminate at Strontian, about twelve miles from the ferry; for half the mountain in which the lead mine of Strontian is situated is gneiss, and the other half granite. The lead ore lies in a vein which separates the gneiss and granite from each other.

Gneiss frequently alternates with mica slate. When this is the case, the gneiss contains much mica, and gradually passes into mica slate. The other beds occurring in gneiss are quartz, often containing garnets; felspar, generally in a soft state, and destitute of potash, or nearly so, constituting in fact kaoline or porcelain clay; porphyry, generally reddish, and having a base of hornstone; granular limestone, though this kind of bed is rare; serpentine, which is said by Cordier to constitute an immense bed in the central gneiss of France; hornblende slate; and greenstone.

Humboldt assures us that he has never seen gneiss at a greater height above the sea than 8900 feet; but this observation can apply only to America, for the central culminating point of the Alps consists of gneiss alternating with granite, and rises to the height of 12,201 feet. This point is called the Grosse Glockner, and is situated a little to the west of Carinthia and Salzburg.

A considerable number of the western islands of Scotland consist of gneiss. This is the case with Long Island, Teree and Coll. There is also a considerable deposit of gneiss on the main land of Scotland, beginning at the south-east point of Morven, opposite to the Isle of Mull, and extending at least as far north as Loch Carron, situated to the north of the Isle of Skye. This tract has been very well described by Dr. Macculloch, in his *Geological Account of the Western Islands of Scotland.* It is evident from the sections which Dr. Macculloch has given, that the gneiss in the north of Scotland lies over quartz rock and *primary sandstone*, if such a name can be given to the granular quartz rocks, which Macculloch considers as sandstone.

Cape Wrath, a most conspicuous promontory at the north-west extremity of Sutherland, contains abundance of gneiss and granite veins. Gneiss also occurs to the north of Loch Broom, in Ross-shire, evidently lying over the quartz rock and primary sandstone of Dr. Macculloch.

Garnets, octahedral iron ore, fluor spar, zircon, tourmaline, epidote, molybdena and iron pyrites occur pretty frequently interspersed through gneiss rocks.

There is a circumstance of almost constant occurrence in gneiss rocks, which deserves to be pointed out. The beds of which the rock is composed are frequently found incurvated in a most extraordinary manner. Some idea may be formed of the nature of these incurvations by supposing the gneiss beds to have been in a plastic state, either from the action of heat or of some other unknown cause, and, while in this state, to have been subjected to pressure at the two extremities, or in some other parts, according to the nature of the curvatures. But even this hypothesis (though the best that has been thought of) will scarcely enable us to explain all the contortions which not merely the beds of gneiss, but likewise of mica slate and clay slate and even greywacke slate, exhibit. There is a bed of clay slate near the ferry to Kerrera, a few miles south of Oban, in Argyleshire. This bed has been partly wasted away by the sea and its structure exposed to view. It contains a central cylindrical nucleus of unknown length (but certainly considerable), round which six beds of clay slate are wrapt, the one within the other, so as to form six concentric cylinders. Now, however plastic the clay slate may have been, there is no kind of pressure which will account for this structure; the central cylinder would have required to have been rolled six times in succession (allowing an interval for solidification between each) in the plastic clay slate.

When gneiss, mica slate or clay slate lie incumbent on, or in contact with granite, we frequently observe veins of granite penetrating through these rocks, and sometimes passing a considerable way. These veins are not more than a few inches wide; they were observed by Dr. Hutton in Glen Tilt, and have been recognised since as so exceedingly common, that hardly any extensive junction of granite with other rocks is to be met with in which granite veins may not be traced. One of the most remarkable of these localities is St. Michael's Mount, Cornwall. This mount consists of a cone of granite, wrapt round by clay slate, of which the neighbouring country consists. Veins of granite not less than 124 feet in length, and becoming gradually less than an inch in thickness, may be perceived running into the clay slate, especially on the east side of the Mount.

CHAP. XV.

GRANITE.

Granite, from the beauty of the stone and from the majestic elegance which in general characterizes the mountains composed of it, has always occupied a prominent place in geological descriptions of the earth. It was long a controversial subject whether or not granite rocks be stratified, but the point has at last been decided in the negative; what has been called *stratified granite* is, in reality, *gneiss*. Both rocks, indeed, are composed of the same constituents, but the former is granular while the latter is schistose.

The term *granite* is supposed to be derived from the Latin word *granum*, and to have been given to this rock from its granular structure. Werner used to affirm that it was first used by Tournefort in his *Voyage to the Levant;* this book did not make its appearance till after Tournefort's death, an event which took place during the year 1708. Tournefort uses the word in his account of Mount Cynthus, in the island of Delos, which he says is nothing else than a block of *granite* of the ordinary sort, common in Europe. He says that there is scarcely an island in the Archipelago that does not abound in granite, and that the Romans used to fetch great quantities of it from the island of Elba, on the coast of Tuscany, and also from the quarries of Upper Egypt. It is obvious from all this that the word *granite* was in common use in Tournefort's time, at least in France, and that it was by no means first used by him. I have looked into several older writers without finding any trace of the term. To Pliny it was unknown. It does not occur in Agricola, nor is any trace of it to be found in the early volumes of the *Philosophical Transactions*, or the *Memoirs of the French Academy*. In the first volume of *Birch's History of the Royal Society*, p. 80, the following passage occurs, copied by him from the registers of the Society for 1662.

"Mr. Winthrop produced malleable mineral lead and a piece of a rock of *granite*."

Upon turning up this passage in the original register of the Royal Society, still preserved in their apartments, I found that the word was not written *granite* but *granate*. Now, this was the usual expression at the time for what we now call *garnet*, but in the English translation of Tournefort's voyage, published in 1742, the word is also spelt *granate*. I think it probable that the term *granate*, in the passage above quoted, referred to the rock which we at present distinguish by the name of *granite;* had it referred to a garnet, it is not likely that the term *rock* would have been applied to it. If this be admitted it is the oldest example that I have met with of the application of the term in its modern acceptation.

Granite is a granular rock composed of three ingredients; namely, *quartz*, *felspar* and *mica*. These three constituents are in crystals more or less regular, and are mixed together and cohere without any visible cement and without any thing like regularity in the proportion of the constituents. The felspar is usually the most abundant ingredient, and as it occurs of various colours and of very various sizes, it is to it, chiefly, that the great diversity in the appearance of granite is owing. Instead of felspar, albite is often substituted, and in many varieties of granite, both felspar and albite occur together. The colour of the mica in granite is most commonly dark brown, almost black; but it occurs also colourless, in beautiful silky scales. Sometimes hornblende assumes the place of the mica; the rock is then called syenite from Syena, in Egypt, where this kind of mineral was quarried by the ancients and employed for ornamental purposes. It is not uncommon to meet with syenite containing both hornblende and mica, and therefore composed of four instead of three ingredients.

It was the opinion of Werner that syenite was distinguished from granite by its position, being considerably higher in the series of rocky formations; but this opinion does not seem likely to be verified by more extended observations. In this country syenite occurs in Galloway in three places nearly in a line with each other, and with the granite tract in the island of Arran. The first of these is the Criffle, a very conspicuous mountain to the south of Dumfries, and at the eastern extremity of the County of Kirkcudbright. The second locality is called the *Dee tract;* it begins at Loch Ken and extends about nine miles west, with a breadth of about four miles. The third tract is at Loch Doon, on the borders of Ayrshire; it is of the same extent as the Dee tract and similarly situated. These three syenitic deposits are partially covered by clay slate rocks, which lie over the syenite in an inclined position. I am not sure that any fossil remains have been found in this slate, yet it has been generally referred to the transition series.

There is a syenitic hill, called Mount Sorrel, which occurs in the tract in Leicestershire called Charnwood forest. This tract consists of clay slate rocks, rising through a new red sandstone country. These slates resemble exactly the Welsh slates, and, like them, are employed for roofing. It is probably transition slate, and the beds of it recline against the sides of the syenitic hill of Mount Sorrel. This remarkable tract constitutes a kind of triangle, the three sides of which are, respectively, nine miles, nine miles and six miles.

But the granite which constitutes the base of Ben Nevis seems also to be a syenite. Now, there can be no doubt that gneiss, mica slate and clay slate follow in regular order of position over this rock.

The constituents of granite are sometimes of a very small size, so that we can just distinguish them from each other by the naked eye. The rock is then called *small-grained granite.* This is pretty much the case with the granite found in the neighbourhood of Aberdeen, and employed in that part of the country as a building stone. The principal quarries from which the stone is taken, are the *Dancing cairn*, about three miles north-west from Aberdeen, near the Don and Inverury canal, and Rubislaw, about a mile beyond the town on the great south road. The appearance of the blocks in situ, resembles very closely that of a basalt or greenstone quarry. In this granite, when the felspar is red, the grains are usually large, when white, small. The red grains are *felspar*, but I have not been able to procure the white grains in a state fit for analysis. They are probably *albite*. The Aberdeen granit constitutes a very durable and beautiful building stone; bu in consequence of its extreme hardness, the masons were lon unable to carve out of it the usual architectural ornament Hence, in Aberdeen, the doors and the windows were lon destitute of every thing ornamental, being mere holes in th wall. But they have gradually acquired the requisite skil and in the new houses, granite pillars, pilasters, and column are beginning to make their appearance.

When large crystals of felspar are interspersed throug small-grained or medium-sized granite, the stone is said to b porphyritic. This is the case with that portion of Cornis granite which occurs in the neighbourhood of Redruth. Th foot pavement of Westminster bridge consists of this granit The slabs are long and have been worn quite smooth by th feet of passengers. When this pavement has been wash clean by a shower of rain, these large crystals of felspar of flesh colour, and from 3 to 6 inches long, may be very di tinctly seen in the granite.

One of the most beautiful varieties of granite that I ha seen, occurs at the south-west end of the island of Mull, lar blocks of which may be seen on the contiguous island Icolmkill. The felspar is flesh-red, the quartz white, and t mica not abundant. Nearly the same kind of granite occu at Balechulish, on the south side of Loch Linné, at the nort ern extremity of Argyleshire. The granite of Strontian a Ben Nevis approaches more in appearance to the Aberde granite, except that the grains are larger.

The great granite tract in Scotland is in the neighbourho of Aberdeen. The primary country begins in Kincardineshi soon after passing the river at Stonehaven. Gneiss first mak its appearance; but before we come to the Dee the gnei passes into granite. The granite tract extends from the D to the Don, where gneiss occurs intermixed with mica slat and somewhat farther north, the mica slate passes into cl slate. The Aberdeen granite stretches along the Dee at least sixty-five miles west, as far as Brae Mar, at which place it is occasionally mixed with gneiss and beds of an impure limestone. I do not know, from personal inspection, that the granite continues beyond Castleton; but it probably does, as the lower part of Ben Nevis, which is in a line with the Aberdeen granite, consists of granite. Here it extends over a space at least twelve miles in breadth, and with alternations of gneiss, continues to the west coast of Scotland.

There is another granite tract, which begins at Portsoy on the Murray Frith, and extends as far as Banff. Probably, indeed, it proceeds without interruption to Kinnaird's Head, which constitutes the north-east extremity of Aberdeenshire; but I did not myself trace it farther than Banff.

Another extensive granite tract in Scotland, is in the county of Sutherland. Caithness, the farthest north county in Scotland, is exceedingly flat, and composed chiefly of sandstone and slate clay. It is separated from Sutherland by a high mountainous tract, distinguished by the name of the *Ord of Caithness*. It is about ten miles in breadth, and its greatest height above the level of the sea is not under 1400 feet. The basis of the Ord seems to be granite, but sandstone beds (doubtless connected with the greywacke series) may be seen covering this granite in many places. The east coast of Sutherland, from the Ord to the Dornoch frith, is alluvial, and consists of soil mixed with an immense number of granitic boulders, many of them of great size. Beyond this alluvial portion, sandstone beds occur, recognisable by their fossils for a part of the lias formation. About three miles inland from the coast, granite rocks commence, at first constituting only the under part of the mountains, while their summits consist of sandstone. But as we advance westwards the whole hills become granitic. These granite mountains are in general low, round backed, and barren. How far west the granite of Sutherland extends has not been determined. The westside of the county consists of quartz rocks and a red sandstone, which seems connected with the greywacke series.

A considerable tract of granite exists in the island of Arran, the centre of which is Goatfield. The granite is skirted all round with mica and clay slate. At Loch Ranza, on the north-west side of the island, occurs the celebrated junction of the granite and clay slate, which was so often visited during the controversy between the Neptunists and Plutonists. It was brought into notice by Dr. Hutton, who observed that the clay slate in the neighbourhood of the granite was harder than at a distance from it. This he considered as a proof of the indurating effect of the granite while in a state of fusion upon the clay slate. The granite of Galloway has been noticed already.

Granite occurs in the mountainous tract in the south of Roxburghshire, which separates England from Scotland. I have seen specimens of the granite, but never having visited the spot, can give no account of its extent and situation.

Granite constitutes a very conspicuous rock in Cornwall and Devonshire, and makes its way to the surface in certain isolated places. The Land's End consists of granite cliffs about 230 feet in height. The rock extends, without interruption, to Penzance, a distance of about ten miles. It appears in two other places, in a line between the Land's En and Dartmoor. This table land, which constitutes the mountainous part of Devonshire, consists of it. The highest of th Dartmoor hills is Rippontor, which rises to the height of 1,54 feet above the level of the sea. Brown Willie, the next height, is 1,368 feet high.

I shall not attempt to describe the granite formation as appears in different parts of Europe, Asia, and Americ Such a description would occupy a great deal of room witho adding much to our information. I may merely mention th Simplon, the lower half of Table Mountain at the Cape Good Hope, and the neighbourhood of Canton in China, well known examples of its occurrence.

It was long believed that granite constitutes the lowest all the formations hitherto met with on the globe. Hence was considered as the oldest and the fundamental formatio But after a great deal of discussion and observation, it is no generally admitted that this point cannot be maintained. is true that granite occasionally appears under every oth rock; but when we examine the rocks in contact with it, generally find granite veins making their way through the and not unfrequently proceeding a very considerable wa We find beds of granite often interspersed through gneis mica slate, and even clay slate. And in the neighbourhood Christiania, in Norway, Von Buch observed granite lying ov fossiliferous limestone. It is therefore incontestible that it must have been deposited after this limestone.

The opinion now generally adopted respecting granite, is the one originally proposed by Dr. Hutton; namely, that granite has been forced up from below in a state of fusion, and that it has cooled more or less slowly under a great pressure. Hence the reason of its crystalline texture, of the great difference in the size of its grains, and of the beautiful crystals occasionally met with in cavities of the rock. Hence the reason of the granite veins. The forcing up of a fluid mass of matter would naturally alter the position of, and produce rents in, the strata through which it was forced. The liquid matter would of course enter these rents and fill them. When the quantity of fluid granite was large, it might force itself between two contiguous beds, or it might make its way to the surface and be deposited upon the uppermost formation which existed. Hence we may expect occasionally to find granite lying over every formation which existed at the time of its protrusion.

Granite differs very much in its appearance from modern lavas, or even from the lavas of extinct volcanoes of the remotest period. The reason of this cannot be assigned. The stony matter, by the fusion of which it was formed, may have been different. In lavas, we never, or at least very seldom, find quartz crystals. The silica is usually in combination with other constituents of the rock.

CHAP. XVI.

PORPHYRY AND TRAP ROCKS.

Besides the formations which have been already described, there is another set of rocks scattered in great profusion over the surface of the earth. These, so far as is known at present, never contain any fossil remains, either of vegetable or animal bodies. They often constitute the highest portion of the country where they occur, though frequently also they are interposed between the layers of stratified rocks. These rocks have a striking analogy to those of volcanoes; and, after a violent controversy, which lasted for upwards of half a century, it has been finally decided by geologists that they are of igneous origin. These rocks have been divided into the great classes of *porphyry* and *trap*. Let us take a view of each in succession.

I. PORPHYRY.

The term *porphyry* literally signifies *red*, and it was originally applied to certain stones capable of taking a polish, an distinguished by a red colour. Thus Pliny speaks of *marmo porphyrites* as common in Egypt. But mineralogists a present apply the term to all rocks having a compact basis through which are scattered crystals, or grains of some othe mineral. The nature of the base gives the name to th porphyry. This basis is either

Felspar,	Hornstone, or
Pitchstone,	Clay stone.

The crystals are usually felspar or quartz, sometimes mic or hornblende.

Felspar porphyry and claystone porphyry are found in bec among the transition rocks. Whether they exist among th primary rocks is not so clear; I am not aware of any we authenticated example of it. There is a bed of clayston porphyry in the valley of Magdalena, between Guambos an Truxillo, in Peru, which reposes upon granite, but it is covere by a secondary quartz rock.

Transition porphyry constitutes one of the most abunda rocks in South America. There can be little doubt that po phyry, like trap, has made its way from below in a liquid stat and has, in that way, insinuated itself through the beds whe it occurs. It would therefore be an object of some interest determine the lowest rock over which it lies, because th knowledge of this would give us some idea respecting the e of its eruption.

It constitutes the uppermost conical summit of Ben Nevi and seems to have been forced up in a state of fusion throug the granite of which the inferior portion of that mountain i composed. Hence it may be inferred that it is of posterio formation to granite, and many other circumstances lead t the same conclusion. The Ben Nevis porphyry spreads itse a good way to the south and caps the summit of many mountains in the neighbourhood. Whether it constitutes the summit of Ben Cruachan I do not know, having been disappointe by the weather in my attempt to ascend that mountain.

Claystone porphyry is very common in our mountain ranges in Scotland, which are connected with the secondary and transition formations. It constitutes the summit of all the eastern part of the Pentlands, on the south and south-east of Edinburgh; it is also pretty common in the Ochils. No transition beds have been observed in this chain of hills, but they rise up from under the coal beds, and therefore have been elevated after the deposition of the great coal basin in the middle portion of Scotland.

The mineral called *pitchstone*, so far as I know, has been hitherto met with only in veins. There are two remarkable localities of it in Scotland, namely, the Islands of Egg and Arran.

Egg is a small island situated a little to the south of the Isle of Skye. It is composed chiefly of amygdaloid, according to Dr. Macculloch; but towards the south end of the island, there is a high ridge or dyke, which traverses it from west to east. This ridge is known by the name of the *Skune of Egg*. This dyke, or wall, is about 300 feet high on the east side, and so precipitous as to be inaccessible. It is composed of pitchstone, or rather pitchstone porphyry, for it contains occasional crystals.

At Brodic Bay, in the Island of Arran, which is the usual landing place, the beds exposed on the surface are composed of red sandstone, similar to what constitutes the neighbouring Cumbraes, and which appears on the opposite west coast of Ayrshire. Through this red sandstone run some pretty thick veins or dykes, of leek-green pitchstone. The uppermost bed in the south of Arran, is a clay stone porphyry. It is probable that the pitchstone dykes, notwithstanding the great difference in their appearance, are nearly of the same era as the claystone porphyry.

I am not aware of the existence of hornstone porphyry in any part of Great Britain; it is obviously rare.

II. TRAP ROCKS.

The word *trap* was first applied to rocks by Rinman, in a paper *On Stones containing Iron*, inserted in the *Memoirs of the Stockholm Academy* for 1754. He imposed the name, he says, because the rocks alluded to broke in rectangular fragments like *sandstone.*[*] Werner afterwards limited the

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[*] The Swedish word *trappa*, signifies a stair. The name was doubtless

signification to certain rocks distinguished by the hornbl which they contain. At present the term is applied to a rocks which penetrate through others in the form of dykes to those which cover the summits of the other rocks as does. The most important of these rocks are the follow

1. Greenstone,
2. Serpentine,
3. Diallage rock,
4. Amygdaloid,
5. Basalt,
6. Porphyry slate,
7. Wacke,
8. Trap tuff.*

1. *Greenstone*, called by the French *diabase*, is a mixt felspar and hornblende, or sometimes of felspar and a It is granular, and differs much in the size of its constitu Sometimes they are so small as hardly to be distinguish the eye, and sometimes in large, and almost regular cry The hornblende predominates, and usually gives the st greenish shade. Hence the reason of the name *green* imposed on it by Werner.†

This rock is exceedingly common in the coal distri Scotland. Many hills in the neighbourhood of Edinburg the Castle hill, Salisbury Crags, Arthur's Seat, Inchkeith contain masses of it not stratified, but frequently split columns, sometimes of great size. The most remarka these are the columns in Fingal's Cave, in the Island of S and the Giant's Causeway, in the north of Ireland. Dyk greenstone are abundant on the west coast of Ayrshire also in Lorn, near Oban. In England it is not so abun yet it occurs in the transition formation in Cumberla well as in the range of Scottish mountains, from St. Head to Loch Ryan. In the neighbourhood of Birmin a number of little hills of greenstone and basalt occur, are employed in that country in paving the roads. streets of Birmingham itself are paved with stones from quarries. Indeed greenstone and basalt constitute the best materials for mending roads, and last so much lo than the flints employed for that purpose in the neighb

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imposed from the *stair-like* appearance which some of the most rema of the Swedish trap rocks exhibit.

* Of these, *serpentine* and *diallage* rocks are not usually reckone rocks. But I place them here from their analogy with the other because I conceive that they owe their origin to the same cause traps, namely, *heat*.

† Beudant has shown that greenstone is usually a mixture of f albite, amphibole, and sometimes of pyroxene, and even of other mi See his analyses, Ann. des Mines (second series), v. 300.

hood of London, that Mr. Macadam is of opinion, they are worth three times the price of these latter materials.

2. *Serpentine*, called *ophites* and *variolites* by the French, is a well characterized mineral, which has been described in a preceding part of this work. Serpentine rocks are all massive without the least indication of stratification. We have two localities of serpentine rock in Great Britain; namely, the peninsula of the Lizard, in Cornwall, where it is associated with greenstone, and occurs in clay slate rocks; and Portsoy, in Banffshire, where it occurs in granite. It is a common rock in various parts of Italy, particularly near Genoa and Turin. In France it is rare, but it is found at Abeille, near Limoges, and in the Pyrenees. In Germany it occurs at Zöblitz. In the United States of America, it is found near New Haven in Connecticut; but the most celebrated locality is Hoboken in New Jersey, not far from New-York.

3. *Diallage rock*, is a mixture of diallage and Saussurite. It is called *gabbro* by the Italians. It is a beautiful rock, usually associated with serpentine. Accordingly, it occurs in the Lizard in the serpentine of that district, and in the serpentine rocks in the north of Italy. From the circumstance that diallage usually occurs in serpentine, it has been considered by some as crystallized serpentine; but the constitution of the two minerals is incompatible with that supposition.

4. *Amygdaloid*, is a name given to a rock consisting of a compact basis, and containing numerous almond-shaped cavities, usually filled up with minerals, differing in their nature from the rock in which they occur, and these minerals usually form groups of crystals more or less perfect; and, what is curious, water is a very common constituent of these crystals. The basis is sometimes claystone, sometimes wacke, and sometimes greenstone. The minerals contained in the cavities are calcareous spar, chalcedony, agate, quartz, green earth, and the whole tribe of zeolites, amounting to not fewer than twenty-four species. The zeolites always contain water as a constituent, but the calcareous spar and quartz are anhydrous.

Amygdaloid is a very common rock in Scotland, in that part of the country where trap abounds. The hill of Kinnoul at Perth, is an amygdaloidal rock. It abounds in the Ochils, and is very common in the Campsie and Kilpatrick hills, and also in the high country to the south of Greenock.

5. *Basalt*, is a black compact rock of considerable hardness and weight. It almost always contains imbedded grains of

olivine and augite, and frequently other crystals. It is and answers admirably for mending the roads. Its c ents, as determined by the analysis of Dr. Kennedy,*

Silica, . . .	48
Alumina, . . .	16
Lime, . . .	9
Soda, . . .	4
Protoxide of iron, .	16
Muriatic acid, . .	1
Water, . . .	5
	99

Basalt and greenstone are usually associated togeth appear in fact to be little else than two different states same mineral. They have both a strong tendency to a columnar form. Many of the columns at the Causeway and Staffa, approach nearer basalt than gree These columns are usually hexagonal or pentagonal, regularity of the jointing is often surprising. Colu basalt are not uncommon in Fife, and a tendency to th form may be seen in the Castle Hill of Stirling. The ern declivity of Arthur's Seat, near Edinburgh, exhib columnar form in considerable perfection.

6. *Porphyry slate*, has for its basis the mineral name *stone*,† (*eurite* of the French) from the metallic sound w emits when struck with a hammer. It has usually a gr grey colour, though sometimes it is brownish-red. Th fracture is dull and splintery, principal fracture glim and slaty. This characterizes clinkstone. This rock c in it crystals of glassy felspar, which gives it a porp structure.

Porphyry slate is common in East Lothian, which only part of Great Britain where I am aware of its exi The county in general is composed of new red san through which a number of conical or round backe make their way, and these hills are either composed o phyry slate, or at least contain it as one of their consti

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* Edin. Phil. Trans. v. 89.

† M. C. G. Gmelin has shown that clinkstone is a mixture of fels a zeolite, usually mezotype. Muriatic acid decomposes the zeol leaves the felspar, which may be afterwards analyzed separately. these analyses may be seen in the Annales des Mines (second se 298.

The most conspicuous of these hills is North Berwick Law, constituting so remarkable an object from Edinburgh. This hill rises from the sea-shore about twenty-two miles east from Edinburgh, it is conical, and probably 800 or 900 feet high. It seems composed entirely of clinkstone and porphyry slate, which sometimes assumes the aspect of claystone porphyry and sometimes of compact felspar.

Trapren Law is a low round-backed hill situated about eight miles south of North Berwick Law. It is about 360 feet high, very steep on the south and west sides, but much less so and covered with grass on the north and east sides. It is composed of clinkstone, generally porphyritic. It has a slaty structure, and the position of the slabs is nearly perpendicular. The slates are thick, and from their splitting in blocks the south side of the hill has a columnar appearance. The old castle of Dunbar is situated upon a rock surrounded by the sea, and about six miles east from Trapren Law. It is a hard rock, having the aspect and the metallic sound of clinkstone, but is so much injured on the surface by the continued action of the sea, that it is difficult to make out the species of rock of which it was originally composed. The old pier of Dunbar is built upon a red coloured stone split into five-sided columns, and doubtless also a variety of porphyry slate. At North Berwick the porphyry slate is obviously associated with amygdaloid, greenstone, and claystone porphyry. The Girleton hills, situated between North Berwick and Haddington, are said to be composed also of porphyry slate. But I have not had an opportunity of examining them.

The constituents of clinkstone, as determined by Klaproth,* are

Silica, . . .	57·25
Alumina, . . .	23·50
Lime, . . .	2·75
Soda, . . .	8·10
Protoxide of iron, .	3·25
Protoxide of manganese,	0·25
Water, . . .	3·00
	98·10

7. *Wacke* is a soft mineral intermediate between basalt and clay. It has a greenish grey colour, and becomes harder

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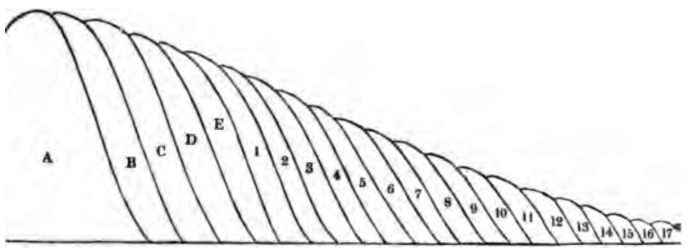
* Beiträge, iii. 229.

when long exposed to the air. It has no lustre, but befo the blowpipe melts like basalt, showing that in its compositi it bears a considerable resemblance to that mineral. It oft contains crystals of hornblende and mica. When this is t case it is harder than usual, and approaches somewhat basalt in its appearance. One of the localities where wac could be best seen was the Calton Hill at Edinburgh, after had been cut through for the new London road, and befo the rock was concealed as it now is by the buildings of t High School.

The Calton consists of alternate beds of claystone porphy and of trap tuff. It is steep and almost precipitous on t south, north-west, and north sides, but the east side exten a considerable way, and slopes gradually down into the pla This sloping portion is composed of alternate beds of wac and shale. The following ideal section of the hill will co vey some idea of its structure :—



A. Claystone porphyry,
B. Trap tuff,
C. Claystone porphyry,
D. Trap tuff,
E. Claystone porphyry,
1. Shale,
2. Wacke,
3. Sandstone,
4. Shale,
5. Wacke,
6. Shale,
7. Wacke,
8. Shale,
9. Wacke,
10. Shale,
11. Wacke,
12. Shale,
13. Wacke,
14. Shale,
15. Wacke,
16. Shale,
17. Wacke,
18. Shale.

From this alternation of wacke and shale I think it unlikely that wacke will be ultimately found one of the co stituents of the coal metals rather than be associated with t trap rocks, to which however it is obviously also related.

8. *Trap tuff* as a rock may be considered as a kind of coarse sandstone made of portions of the other trap rocks, basalt, amygdaloid, sandstone, cemented together by a loose spongy clayey basis often much iron-shot. The masses vary much in size, and are often enormous, so that the rock cannot be well studied except in situ.

Beds of trap tuff occur in the Calton Hill at Edinburgh. The highest part of Arthur's Seat, and a considerable portion of the south shoulder of that hill are composed of it, also one of the farthest west of the Ochil hills is likewise partly composed of it, and a fine section of trap tuff is laid open by the road which passes on the west side of Airthrey to the Sheriff Moor.

These trap rocks seldom appear in the formations which lie over the coal measures. There are indeed a few examples of these rocks in the new red sandstone. Along a line of from five miles north to five miles south of Exeter, many points occur in which masses of amygdaloidal trap are found interposed between the beds of the new red sandstone. They are near the lowest part of the sandstone, but decidedly in it, and in a conformable position, and not in the transition beds which lie immediately below. This rock is granular, has a purplish brown colour, and contains imbedded in it great quantities of fragments of calcareous spar and mica slate, sometimes tinged by copper and sometimes by manganese. The amygdaloidal cells are filled with oxide of manganese, calcareous spar, and coarse jasper. The compact portions of this rock fuse before the blowpipe, sometimes into a black glass, and sometimes into a white enamel.

There occurs also a basaltic dyke near Cleveland, extending from the coal across the oolitic chains. The great greenstone dyke in Strathearn, which crosses the road between Muthil and Crieff passes through new red sandstone.

The great body of trap occurs in dykes which intersect the coal measures, and have obviously produced great alterations in the position of the beds. It must therefore have been of posterior origin, and the example of the Cleveland and Strathearn dykes proves that sometimes at least the difference of age is very considerable. In the western islands of Scotland, Dr. Macculloch has shown that the trap occupies a position superior to the lias; and on the north-east coast of Ireland we find it lying over chalk. From all this it is evident that the irruption of trap rocks must have taken place during a vast series of ages. Yet, the greatest quantity seems to have made its appearance after the deposition of the coal measures, and before that of the new red sandstone.

No organic remains, either mineral or vegetable, have yet been observed in the trap rocks of Great Britain. But Dr. Richardson discovered ammonites in a black rock about four miles from the Giant's Causeway, which he considered as basalt, but which in fact has more the appearance of an indurated clay. Mr. Weaver informs us that he has discovered shells of the terebratula in the greenstone associated with the mountain limestone of the centre of Ireland. It would appear from these discoveries, that though petrifactions are very rare in trap rocks, yet they are not absolutely wanting.

The trap rocks connected with the coal measures occur in three distinct modes of position. Two of these appear to indicate an origin distinct from that of the strata with which they are associated, while the third countenances the opposite inference of contemporaneous formation.

1. They occur as overlying masses resting unconformabl on the subjacent strata. This is a common occurrence in th counties of Edinburgh, Stirling, and Fife, and indeed in th whole coal country of Scotland.

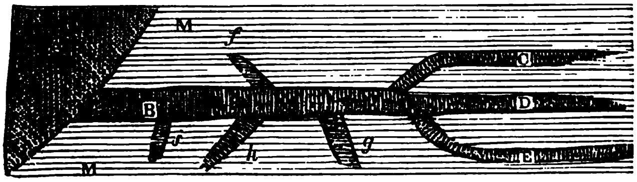
2. As dykes irregularly intersecting and traversing th strata. Numerous examples of this occur in all our co fields. And in the same way are they found traversing fo mations older than the coal. Thus, on the south of Oba they traverse the transition conglomerate of that country, a probably also the clay slate, though that is not so satisfactori established. A little to the south of Aberdeen there is greenstone dyke which cuts through the granite, and may traced a considerable way west. A similar greenstone dyk traverses the granite at Newry, in Ireland.

3. As beds conformably interstratified, and regularly alte nating with the other strata. The great whynsill of Northum berland and the toadstone strata of Derbyshire illustrate th case. The whynsill is 120 feet thick, and is said to consis of a basaltic greenstone. It is the 192d bed from the surface and is 840 yards below the level of the height of the Nor thumberland beds.

Between the trap rocks occurring in these three so differen positions, no mineralogical or external features of distinctio have been shown to exist. The same varieties seem to occu indiscriminately in each.

When trap exists in beds alternating with, and conformable to, the beds in which it is placed, it has been asserted that it is subject to much greater alterations in thickness than is the case with the other beds. It has also been said that the metalliferous veins traversing the other strata are themselves cut off by the trap beds. Hence it has been inferred that they are of subsequent formation to the beds in which they occur. But the metalliferous veins themselves are subject to such alterations in width when they pass through different strata, that it would not be safe to rely upon these disappearances as a proof of posterior formation. It may be, as it has been affirmed, that in these cases the metalliferous veins are not completely annihilated, but merely reduced to very minute strings.

But Dr. Macculloch has shown in his account of the coast of Trotternich, in the Isle of Skye, that trap in the same place may appear in all these three states, and of course that no conclusion relative to its origin can be drawn from its position. He noticed a large mass of trap rising through, and on one side overlying the sandstone strata. From this mass a horizontal bed was detached running conformably through the midst of the strata. This was ultimately divided into three beds, also conformable, and alternating with the sandstone. Dykes also proceed in several places from the single bed of trap. The following diagram exhibits a section of this appearance :—



A, mass of trap lying over the sandstone, M. B, a bed of trap proceeding from A, passing in a conformable position through the sandstone, and finally splitting into the three subordinate beds, C, D, E; *f*, *g*, *h*, *i*, dykes of trap proceeding from the bed, B.

The general opinion of mineralogists is, that trap rocks have been forced up from below in a state of fusion, and that they have thus made their way through the beds with which they are connected. Several circumstances have been pointed out which strongly corroborate this opinion. The strata through which trap rocks pass are generally found indurated in the immediate neighbourhood of the trap dyke; loose grits pas into compact quartz rock, and shale into flinty slate. Coa under similar circumstances, is converted into coke, as if b the volatilization of its bituminous matter.

The most remarkable trap bed known, is the whynstonesil in the Northumberland coal measures. It may be seen ne the lead mines on Dufton fell, upon the great western escar ment of the mountain range connected with Cross fell. It is greenstone bed, composed of white felspar and greenish-bla hornblende, and from the prevalence of the latter it has greenish colour. Its thickness is very irregular, being on 6 fathoms in some places, and 20 or even 30 in others. Tl trap bed is believed to be the same which is laid open to vie in the valley of the Tees. Here it extends from near t source of the Tees to Eggleston, so that its breadth cannot less than fifteen miles. There are several other basaltic trap beds in the Tees, which occasion cascades, but it wou be tedious to enumerate them.

A bed of basalt is penetrated at the depth of 159 fatho in the Alston Moor mines. This is referred by the miners the whynsill, but whether correctly or not, is doubtful.

At Wratch cliff crag, near Alnwick, basalt occurs confor ably interstratified with the other rocks. The effects produc by this basalt upon the contiguous strata are striking. Lim stone is rendered highly crystalline, and unfit for lime; sl clay is converted into a substance like flinty slate or porcel jasper, and the coal is invariably charred when in contact w it. The sandstone on which it reposes has assumed a bri red colour.

The number of veins or dykes passing through the c measures is very considerable, and there is no uniformity their direction. The circumstances attending them are many cases very extraordinary. The most considerable basal dyke in the neighbourhood of Newcastle is that which pas through Coleyhill, about four miles west of the town. A lo range of quarries has here been opened upon it, in some pla to the depth of 50 feet, and laying bare the entire width of dyke, which is 24 feet. The dyke in this place is vertic the basalt of which it is composed is in detached masses, coa with yellow ochre. The removal of these brings into view t layers of indurated clay, with which the fissure is lined, a which, breaking into small quadrangular prisms, are us by the country people for whetstones. In this substan clay ironstone, impressed by the figures of ferns, is very abundant.

The upper seam of coal is here found at about 35 feet from the surface, and where in contact with the dyke is completely charred, forming an ash-grey porous mass, which breaks into small columnar concretions, exactly like the coke obtained by baking coal in close iron cylinders in the process of distilling coal tar. Calcareous spar and sulphur are disseminated through the pores of this substance.

The basalt itself, when broken, is of a greenish-black colour, and a coarse-grained fracture. It contains quartz, calcareous spar, and a peculiar mineral not yet examined chemically.

Passing to the east-south-east of the Coleyhill dyke in the line of its direction, a vein is found traversing Walker's colliery, and crossing the Tyne at Walker. This dyke is well defined. It occasions no alteration in the level of the coal strata, and the depth at which it intersects them is unknown. It has been cut through by horizontal drifts in four places. On each side of it the coal is converted into coke, to a depth which on the one side was found to be 18 feet, and on the other upwards of 9 feet. A firm, hard and unbroken vein of basalt, on an average about 13 feet thick, was in immediate contact with the coke on each side; and between these two veins lay nodules of basalt and sandstone, upwards of 9 feet in thickness, imbedded in a cement of blue slate.

At Walbottle Dean, five and a half miles west of Newcastle, below the bridge on the western road, a double vein of basalt crosses the ravine in a diagonal direction, passing nearly due east and west. It underlies at an angle of 78°, and cuts the coal strata without altering their dip. On the eastern bank of the ravine it is laid bare from the level of the brook to the height of about 60 feet. The northern and southern basaltic portions of this vein, the one 5 and the other 6 feet in thickness, are here 13 feet apart, and are separated from each other by a confused heap of fragments of shale and sandstone, broken from the coal strata. With these fragments are found balls of basaltic tufa, parting into concentric layers, and of a light brown colour. The balls are most abundant on the sides of the rubble near the basalt. In a neighbouring colliery both portions of the vein hold their course through the seam of coal, which is charred by their influence. This basalt contains nodules of quartz and chalcedony, but no *adularia*, which is abundant in the basalt of Coleyhill.

A dyke, called the Cockfield dyke, underlies to the south, and throws up the coal measures on that side 18 feet. The low main coal contiguous to the basalt is only 9 inches thick, but enlarges to 6 feet at the distance of 150 feet from it. The coal is reduced to a cinder, and the sulphur is sublimed from the pyrites near the dyke.

A dyke is seen on the banks of the Tees, a little below Yarm. It there passes into the new red sandstone, and continuing its course in the same direction is well known to traverse the north-eastern part of Yorkshire, near the still more recent formations of lias, and the sandstone of the inferior oolite in the eastern Moorlands, on its way to the German Ocean. This dyke is rendered highly interesting by its great length, and the proof it affords, by thus penetrating later rocks, that it must have owed its origin to causes in action long subsequent to the formation of the coal. Analogy leads to the conclusion that the other dykes in the coal are likewise of subsequent origin. It is a dark greyish brown basalt, which turns brown on exposure to the atmosphere. It is the principal material for the roads in the district called Cleveland.

In Derbyshire the trap rocks occur in a bed alternating with the mountain limestone, which, by their interposition, they divide into four separate beds. But other masses of trap, of more limited extent, are occasionally found contained within the limestone beds, especially in what is called the third limestone.* An instance of a dyke is also mentioned by Whitehurst. It has not been ascertained whether these occasional masses of trap be in any way connected with the principal strata. The upper *toadstone* exhibits in Hockley lime quarry, south of Ashover, portions of limestone imbedded in its mass, and some other probable examples of the same kind are cited by Mr. Farey; and Professor Buckland observed the nodules of limestone thus imbedded to be occasionally surrounded by a thin crust of fibrous calcareous spar, exactly resembling that produced in the instances of incipient fusion under pressure, in Sir James Hall's experiments.

The Derbyshire toadstone is an amygdaloid consisting of a compact reddish-brown coloured paste, containing nodules of various sizes, from small granular dots to the size of a hazel nut, or larger. They consist of whitish calcareous spar and of green earth. Agates occur sparingly, affording specimens

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* They are reckoned from the surface.

of onyx, chalcedony, jasper and quartz crystals, usually called *Derbyshire diamonds;* zeolites also occasionally occur. The decomposition of the imbedded nodules causes the toadstone frequently to assume a vesicular lava-like character. This amygdaloid occasionally passes into ordinary basalt, which is sometimes columnar, as at Cavedale, near Castleton.

Mr. Whitehurst maintained that the metalliferous veins of the limestone strata were universally cut through by those of the toadstone, and produced this as a conclusive proof of its subsequent origin. Mr. Farey admits this to be the general fact, but adduces several exceptions, mentioning no fewer than nineteen instances in which the toadstone beds carried ore; usually, however, only in thin strings. More lately the veins of the Seven Rokes mine, near Matlock, which had before been worked in the second and third limestone, have been pursued with success in the intervening toadstone.*

The average thickness of the first or upper toadstone is about 60 feet; of the two lower 75 feet each. This, however, is subject to very great variations.

The district is described by Mr. Farey as bounded on three sides (south, west and north) by an extensive fault, the effect of which is in these directions to place the fourth or lowest limestone on the same level with the shale, the true place of which, as ascertained on the eastern side, is above the whole limestone series. Hence, while the three toadstone strata form nearly parallel bands along the eastern side, where the beds crop out in regular succession, we must not look for any repetition of them on the western side, where the lowest bed is abruptly brought into contact with the shale, necessarily excluding the intervening beds.

The third toadstone bed occurs on the north-western border of the district, where it is repeated with an opposite or north-western dip, underlying the insulated portions of the third limestone. Of these portions one extends from Dolehole, about a mile and a half to the eastward, to Sparrow pip, near the celebrated ebbing and flowing spring. The other includes the villages of Buxton and Fairfield.

In the north-east the third toadstone commences on the border of the limestone tract near Castleton, where it is first

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* Mr. John Taylor, in a late communication to the British Scientific Association, affirms that the veins constantly pass through the toadstone, but that they generally contain no ore. This was the reason why they were considered as interrupted by these toadstone beds.

seen in Cowler hills, and then crosses the ravine called Cave-dale. Hence it ranges in a sinuous line south-west towards the river Wye, thence along the country in a south-west direction to the extremity of the limestone district. The two other beds of limestone have nearly a similar direction; but, of course, are lower in the series. A minute description would not be understood without a map of the district; it will be sufficient to refer to Mr. Farey's *Survey of Derbyshire*, where the whole course of these beds is particularly detailed. The subject is highly worth the attention of future observers, because the assertions of Mr. Whitehurst, if verified, would go far to demonstrate the igneous origin of trap.

Several trap dykes occur in the neighbourhood of Glasgow, one in particular about five miles east on the Stirling road, which alters the dip of the beds on the east of it. After the particulars given respecting the dykes in the Newcastle coal measures it would be tedious to enter into the same details about the Glasgow dykes and those on the west coast of Ayrshire and near Oban, where, however, the nature and effects of these dykes may be studied with great advantage.

Dykes of trap are uncommon in granite though they sometimes occur in it. I have already mentioned the greenstone dyke passing through the granite a little to the south of Aberdeen. It disappears, or, at least, cannot be traced beyond the *Brig of ae hair*, though probably it extends a considerable way inland.

Thus, it appears that the trap rocks cut through or overlie all the formations, from the granite to the chalk; they must, therefore, have been of posterior formation to all of these beds. It is obvious, from the facts stated, respecting the trap dykes cutting through the coal measures, and being covered by the magnesian limestone, that many of these dykes must have assumed their present situation before the deposition of the magnesian limestone; others not only cut through the magnesian limestone, but even penetrate through the lias and the sandstone of the inferior oolite. It is clear, therefore, that all the trap rocks were not formed at once, but that the formation of them was continued at intervals through an immense series of ages. The porphyries, in general, are probably older than the grêat proportion of the trap rocks, though we have no good data to determine the point.

Trap dykes are not the only foreign matter that may be seen passing through the regular stratified rocks in a direction nconformable to their stratification. Almost all the stratified cks, owing, probably, to a force applied to them from below, d by which they have been elevated from the bottom of the a to their present height above its surface, have been subcted to *cracks* or *clefts*, the two portions having separated a greater or less distance and left an open space. When is space continues empty it is called simply a *cleft*, but when is filled with extraneous matter, as it frequently is, it is lled a *vein*. Veins then are merely clefts of the strata afterrds filled up with extraneous matter. Hence it cuts through e strata of the rock in which it occurs, and it may assume ery possible direction according to circumstances; it may perpendicular, or it may approach the horizontal, or it may p at any angle. In general, veins are widest above and beme gradually narrower as they proceed downwards, though e very contrary of this sometimes happens, veins being casionally met with widest below and gradually narrowing they approach the surface.

Sometimes two or more veins cut through the same stratied rock at the same time. Thus, in the lead mine district f the north of England, which is situated in the coal formaon, or at least in the millstone grit and mountain limestone tuated below these measures, the lead ore exists in a set of eins which run east and west. These veins are commonly ery narrow while they pass through the sandstone beds, but the limestone they swell out frequently to a very considerble breadth. These veins are filled with galena, blende, uor spar, and occasionally carbonate of iron and calcareous ar, &c. There is another set of veins running through the me beds, but their direction is north and south. Now the orth and south veins cut through those that run east and est; of course they are the newest of the two sets; they re very seldom filled with lead ore, but often with iron pyrites, uartz, &c. There is a remarkable north and south vein, hich appears very conspicuous a little way to the east of the mmit of Cross fell. It is filled with quartz through which good deal of iron pyrites is interspersed; on that account is vein is known to the miners of the country by the name the sulphur vein. In consequence of its great hardness it s stood the action of the weather better than the beds rough which it passes. Hence it rises conspicuously, formg a low wall extending a great way in length.

Sometimes the new veins not only cut through the old ones, but occasion a subsidence of the strata on the one side or an elevation on the other; or, in other words, they constitute what is called a fault. Now as in these cases the old vein, with all its contents, is elevated or depressed as well as the strata in which it occurs, it is clear that the old vein must have been filled and brought into the very state in which it is at present before the new vein was formed.

A great many opinions have been advanced respecting the way in which these veins have been formed. An enumeration of a considerable number of these opinions may be seen in the second chapter of Werner's well known book, entitled *New Theory of the Formation of Veins.* But it is needless to enter into the consideration of these opinions, as they can scarcely be considered as any thing else than conjectures, unsupported by proof. It must be admitted by every person that veins were originally clefts in the strata in which they occur, though it does not appear so evident whether these clefts remained long open, or whether they were filled and formed almost at the same time.

If we were to suppose that a cleft was formed through a series of strata while still under the surface of the sea, it is clear that this cleft would be gradually filled up by the action of the waters carrying to it the loose matter which existed at the time at the bottom of the ocean, under which the cleft was formed. In such cases the vein would naturally be filled by rolled masses or water-worn stones. Now Werner describes a vein of this kind in Danielstollen at Joachimsthal; it was in continuing to work out the vein Elias and carrying on the operation towards the vein Schweizer, that this vein, consisting of rolled pieces, was discovered at the depth of 180 fathoms. This vein was 14 inches thick, accompanied the vein Elias for some time, and was almost entirely composed of rolled pieces of gneiss of different sizes, some of which had acquired a shape almost spherical. Werner afterwards met with a similar occurrence in the *Stoll-Resser*, near *Riegelsdorf* in Hesse, where a vein of cobalt, having a direction nearly vertical, was intercepted by another vein almost entirely composed of sand and rolled pieces. According to the observations made by Mr. Schreiber, veins occur in the mountains of Chalanches near Allemont, in Dauphiné, which are entirely filled with rolled pieces.[*]

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[*] Werner on Veins (Engl. Transl.), p. 65.

When veins have been formed by fused matter forced into them, it is obvious that they must have been filled at once, and almost always from below. In this way the granite veins so common in gneiss, mica slate, clay slate, &c., have been formed. To the same origin we must ascribe the dykes or veins of trap so common in the coal beds, and of which so many details have been given in a former part of this chapter. In such dykes it is no uncommon thing to meet with fragments of the stratified rock, which constitutes the walls of the vein, isolated in the midst of the trap. It must have been forced out of its place by the projecting force of the melted matter, and afterwards enveloped in it.

But the most important veins are those which contain the ores of metals. Almost all the metals are found in veins; though there are some, as iron, manganese and chromium, that occur in beds, while the ores of others which are scarce metals, as those of cerium, titanium, columbium, molybdenum, occur in grains or patches in the older rocks. The ores of lead, copper, tin, antimony, zinc, cadmium, bismuth, and even of silver, usually occur in veins, which traverse sometimes the older and sometimes the newer rocks. Now these metals rarely occur in the metallic state, but in combination either with sulphur, or oxygen, or acids. The veins containing these ores, when they are of any considerable size, are not all filled with the metallic portion, but with some other mineral, such as fluor spar, calcareous spar, quartz, &c., through which the metallic ore is interspersed in grains or strings. But sometimes the structure of these veins is of a more complicated nature, being composed of beds arranged in a direction parallel to their sides; these beds are often crystallized more or less regularly, showing that they have been deposited in succession, and very slowly. Now it deserves attention that, when veins are stratified, the same minerals occur on both sides, at equal distances from the walls of the vein.

Werner gives as an example of this structure the mine of *Segen-Gottes* in *Gregorius*, in the district of Freyberg. In it, reckoning from the middle, which is composed of two beds of calcareous spar in which small druses occur here and there, thirteen beds of different minerals are arranged in the same order on each side of the vein; these are fluor spar, calcareous spar, sulphate of barytes, galena, &c. In the southern vein Gregorius, the two beds which adhere to the sides of the vein are composed of crystallized quartz; next to that, on each side, is a bed of black blende, mixed with iron pyrites; this is followed by galena, brown spar, galena, grey silver ore, red silver ore, sulphuret of silver. The central part, which, of course, has been last filled up, is composed of calcareous spar. It sometimes happens that one or more of the different beds are wanting.*

We are not perhaps capable, in the present state of our knowledge, of forming any very accurate conception of the way in which these veins were filled up. It is obvious, from the appearance of the different beds in the vein, that the filling up has been a very slow process, and that it probably occupied a long series of ages. It may be conjectured, perhaps, that the process took place while the beds in which the vein exists were still under the ocean, that the upper surface of the vein either never had been open, or that it had been closed by some unknown means, and that the successive deposition of the beds on the walls of the vein was owing to a succession of galvanic actions, by means of which the materials were gradually brought from a distance, united together and deposited as we now find them. Hence, perhaps, the reason why the nature of veins differ so much, according to the rock through which they pass. This is admirably exemplified in the galena veins in the north of England, which are so rich in ore in the limestone beds, and so poor when they pass through the sandstone and slate clay beds.

The same thing is observed in Cornwall; when a vein passes through the killas it is rich, but it becomes poor on entering the granite, and *vice versa.* In a part of the parish of Gwenap there exists a bank of reddish killas very considerably inclined. The copper veins regularly traverse this bank and are always unproductive; but they resume their richness in passing through the common killas. At Godolphin the veins are rich in the light blue killas and poor in the dark blue. A Poldice and Huel Fortune the veins become poor in the har blue killas. At Huel Squire the veins of copper are very ric in the soft blue killas, but when they pass through two bed of hard dark killas, the one at the depth of 44 fathoms, th other of 120 fathoms, they become poor.

Some idea may be formed of these galvanic actions by reco lecting, that whenever any agents whatever act unequal upon a metallic body, as many piles are formed as there a

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* Werner on Veins, p. 83.

unequally attached. Suppose a particle of metal and
l in contact in a vein, while an acid of any kind is
, or even any imperfect conductor, as water, action
take place, the compounds within reach of this action
undergo decomposition according to the usual law;
xygen, chlorine, &c., would be collected round the
pole, while alkalies, and metals, and bases would be
ed round the negative. These depositions might give
o the formation of calcareous spar, fluor spar, carbon-
iron, &c., on the one hand, and of sulphuret of lead,
et of zinc, iron pyrites, &c., on the other.

Robert Fox has lately made some interesting observa-
n the electro-magnetic properties of veins. His galva-
r consisted of a magnetic needle contained in a box
es square and 1 in depth, round which a copper wire,
l with silk, was passed twenty-five times; small copper
ere placed in contact with the minerals in the mine,
se, by means of copper wires (sometimes several hun-
et long), were brought in contact with the two poles
galvanometer. The following are the general results
bservations:—

n a vein running east and west, the direction of the
of electricity was usually from east to west when the
pt to the north, and from west to east when the vein
the south.

n the same vein the current generally flows from more
d stations to those which are situated at a lower level;
contrary takes place when a cross vein of quartz or
terrupts the continuity of the vein between the two
s.

Vhen we compare two veins parallel to each other, the
flows from north to south more frequently than the
y way.

t the mine of Huel Jewel a current was established
n a disc placed at the surface of the mine upon a mass
extracted, and another disc applied to the vein at a
evel. The upper disc was positive, and the deviation
needle increased as the vertical distance of the two discs
reased.*

ther way in which these stratified veins may be con-
to have been filled up is by the filtration of water

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* Phil. Trans. 1830, p. 399.

through them, containing in solution the substances constituting the beds of the vein. In this way we may account for the deposition of beds of quartz, calcareous spar, and even o carbonate of iron.

Whether some of the metallic ores may have been forced u from below in a liquid state we have no means of determinin at present, though this has been a favourite opinion of geologists in all ages. It is clear that this cannot be the case wit stratified veins, nor with veins filled with fragments of rock or water-worn pebbles. Veins forced up from below in state of fusion must fill the cavity with matter of the sam kind, or if there be any difference it must proceed from subsequent crystallization. Now there are very few metalliferous veins that coincide with these necessary appearance Some veins of hematite, of galena and of copper pyrite when very narrow, may be homogeneous, but I suspect not fo any great length.

CHAP. XVII.

VOLCANIC ROCKS.

The term *volcano* is applied to certain mountains which emit smoke from their summits, and occasionally discharge ashes, or stones, or melted stony matter, to which the name *lava* has been given. Such mountains obviously contain an immense quantity of matter in a state of active ignition at a unknown depth below the surface of the earth.

At what time volcanoes first made their appearance on th surface of the globe we have no means of determining; bu that it was at a very remote period is evident from the numerous extinct volcanoes which must have ceased to burn befo the commencement of history, since no allusion whatever h been made to them in the writings of the most ancient autho with which we are acquainted. The extinct volcanoes Italy, in France, in Spain, and on the Rhine, may be me tioned as examples.

The two most celebrated volcanoes in Europe are Vesuvi and Ætna, and there is every reason for believing that bo these mountains had been in a burning state at a very remo period; but no notice is taken of Vesuvius as a burni mountain, by any ancient writer, prior to the great eruption on the 24th of August of the year 79 of the Christian era, so minutely described by the younger Pliny.[*] It must, therefore, at that time have renewed its eruptions after having continued for many ages in a dormant state. Mount Ætna must have been a burning mountain at a very remote period of the history of the earth, yet no allusion whatever to Ætna as a burning mountain is made by Homer. This could scarcely have been the case had this mountain been in a state of activity in his time. An inspection of the mountain leaves no doubt that eruptions of lava had taken place from Ætna long before the time of Homer, who is usually supposed to have flourished about nine hundred years before the Christian era. But it is probable that for a long period before the age of Homer it had remained in a quiescent state. The consequence of this would be that in that rude state of society all recollection of former eruptions would be lost; and hence, doubtless, the reason of the silence of Homer. The earliest writer by whom the volcano of Ætna is mentioned is Thucydides, who says, that up to the date of the Peloponnesian war, which began in the year 431 B.C., three eruptions of Mount Ætna had taken place since Sicily was peopled by the Greeks.[†]

The earliest volcanic eruption upon record is that by which the cities of Sodom and Gomorrah were destroyed, if we admit with Dr. Daubeny the very probable conjecture, strengthened by the present aspect of the country, that the destruction of these cities was occasioned by a volcanic eruption.[‡] Now, this happened about 1960 years before the commencement of the Christian era. How far the state of Mount Sinai, thus described in Exodus—

"And it came to pass on the third day, in the morning, that there were thunders and lightnings, and a thick cloud upon the Mount ......, and Mount Sinai was altogether on a smoke, because the Lord descended upon it in fire: and the smoke thereof ascended as the smoke of a furnace, and the whole Mount quaked greatly."[§]—

How far this state of the Mount was connected with volcanic eruptions, it would be presumptuous to conjecture; but it is

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[*] Plinii Epist. lib. vi. epist. 16 and 20.

[†] Thucydides Hist. lib. iii. 6, 116.

[‡] Daubeny, on Volcanoes, p. 279.

[§] Exodus, xix. 16, 18.

certain, from the observations of Burkhardt, that abundance of extinct volcanoes exist in the Peninsula of Mount Sinai.

The number of volcanoes at present in a state of activity is very considerable, and shows how great an influence volcani agency has had in elevating the mountains. The number o volcanoes at present or very lately in a state of activity, amount to about 220. Of these an interesting account may be foun in Von Buch's Memoir *On the Nature of the Volcanic Appearances in the Canary Islands, and their Connexion with the othe Volcanoes on the Surface of the Earth.*[*] I shall satisfy mysel here with a bare enumeration of the active volcanoes, with th existence of which we are at present acquainted.

In Europe there are thirteen volcanoes, viz.:—

1. Ætna,
2. Vesuvius,
3. Stromboli,
4. Volcano,
5. Volcanello,
6. Santorino, in the Archipelago,
12. Hecla, and other five volcanoes in Iceland,
13. Jan Mayer, in Greenland.

The volcanoes in the islands connected with Africa (fo none have been observed on that continent itself), amoun only to five; though, if we were to include the extinct volcanoes, they would be much more numerous. These five exis in Teneriffe, the Canaries, Azores, Cape de Verde, and th Isle of Bourbon. Their names are

1. Teneriffe, in the Canaries.
2. Lanzerote, in the Canaries.
3. Fogo, in the Cape de Verde Islands.
4. El Pico, in the Azores.
5. Solazes, in the Isle de Bourbon.

The volcanoes in Asia, and the many islands connected wi that continent, are very numerous, upwards of 130 havi been observed, though many of these are very imperfect known.

From Bruce's account, it would appear that two volcano exist in islands in the Red Sea. It is said also that t active volcanoes exist in central Tartary, and a third in t Himalaya mountains; but the exact situation of these volc noes has not yet been pointed out.

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[*] Poggendorff's Annalen, x. 1, 169, 345 and 514, for the year 1827.

Three volcanoes exist in Kamtschatka, and eleven are enumerated by Von Buch as existing in the Aleutian islands, which lie between Northern Asia and America. There are thirty-seven volcanoes in the Kurile and Japanese islands, and one in the Island of Formosa. Ten volcanoes are enumerated as occurring in the Australian islands; thirteen in the Island of Sunda; twenty-nine in Java; six in Sumatra; sixteen in the Philippines, and five in other islands scattered over the surface of the Pacific Ocean.

The volcanoes connected with the American continent in activity amount to about seventy-four. Of these, ten exist in the West India islands, to which the name of Antilles has been given; sixteen are in Chili; sixteen in the province of Quito; twenty-seven in Guatimala; and five in Mexico.

South Shetland, about 10° nearer the pole than Cape Horn, appears to be a volcanic country. No actual eruptions have been observed; but Mr. Webster informs us that several of the peaks still smoke, and that it abounds in hot springs.*

No doubt this number, great as it may appear, will be augmented when the interior parts of Africa and of New Holland become known. The preceding list is made out chiefly from Von Buch's Memoir, formerly mentioned, and from Dr. Daubeny's excellent work on Volcanoes.† Probably some of the volcanoes enumerated, especially in Java and some other of the Asiatic islands, may not at present be in a state of activity, as that circumstance is not always noticed by Horsfield and Raffles, from whom chiefly the list drawn up by Von Buch is derived.

Numerous as are the volcanoes at present in activity, those which have been extinct for many ages, or which in all probability had finished their eruptions before the earth became fit for the habitation of man, are not less so. One of the first districts containing these extinct volcanoes noticed by geologists is situated on the left bank of the Rhine, not far from Coblentz. A pretty keen controversy respecting the nature of this district, occupied the German geologists for more than half a century, and has been at last decided in favour of those who ascribed the origin of the rocks which constitute the peculiarities of the district to the action of extinct volcanoes.

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* Webster's Narrative, vol. i. p. 152.

† A description of active and extinct Volcanoes, published in 1826.

As many as five distinct craters have been observed, most o which are now filled with water, and constitute lakes. Ther are two volcanic districts, called the upper Eisel and the lowe Eisel; the former is at some distance from the Rhine, but th latter is upon the left bank of that river, between the Mozell and the Ahr. The volcanic rocks of this district cover greywacke bed, which occasionally alternates with limeston The lavas consist of scoriæ, trachyte and basalt, together wit abundance of a matter called in that country *trass.* Its basis composed of pumice, in which are included fragments of basa and other lavas, pieces of burnt shale, slate and sandstone, an numerous trunks and branches of trees. These lavas are deposited on rocks containing lignite, in which five different species of extinct fish, and an extinct species of frog, have been discovered. Hence the age of these extinct volcanoes is uncertain, but Mr. Lyell is inclined to consider them as belonging to the eocene period.*

The extinct volcanoes of Auvergne have acquired still greater celebrity than those on the Rhine. The volcanic appearances in that country are so obvious that they have been generally admitted by all geologists who visited it, and denied only by those who never had an opportunity of examining them. Desmarest, Dolomieu, Von Buch, D'Aubuisson, Lyell, Scrope, have described them in succession, and proved incontrovertibly the existence of extinct volcanoes in that country. The volcanoes exist in three different places, namely, Auvergne, Cantal and Velay. Auvergne contains two distinct volcanic tracts, namely, Monts-Dômes and Monts-Dores. The Cantal lies south from Mont D'Or, and Velay east from Cantal, and separated from it by the river Allier. The following table exhibits the heights of the principal volcanic rocks of that country, determined barometrically by M. Ramond:—†

Cap de Prudelles, . .	2,293 English feet.
Montrodeix, . . .	3,041
Lafont de l'Arbre, . .	2,641
St. Genès Champanelle, .	2,907
La Serre de Fontfrede, .	3,461
Le Puy Girou, . .	2,792
Gergovia, . . .	2,497

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* Lyell's Geology, iii. 200.

† Jour. des Mines, xxiv. 249.

Mont Rognon, . .	2,339 English feet.
Les Côtes de Clermont, .	2,090
Champturgues de Clermont,	1,854
Puy de Cornon, . .	1,765
Montaudou, . . .	1,965
Le Puy de Charade, .	3,018
Gravenère, . . .	2,723
Le Puy de la Vache, .	3,894
Le petit Puy de Dôme, .	4,190
Puy de Pariou, . .	4,009
Puy de Goules, . .	3,803
Le Grand Sarcouy, .	3,793
Le Puy de Dôme, . .	4,846

The volcanic matter so abundant in these countries consists rtly of scoriæ, and partly of basalt and felspar porphyry. he basis of the whole tract is granite. The volcanic matter is probably situated below the granite, and forced up through by the action of fire.

The volcanic country in the neighbourhood of Olot, in atalonia, has not acquired so much celebrity as the two preding tracts, though not less entitled to attention. It was st noticed by Mr. Maclure, and has been accurately described Mr. Lyell.[*] It extends about fifteen miles from north south, and about six miles from east to west; Castle Follet d the river Fluvia being at the north end, while it extends uth nearly to Amer on the river Ter.

The eruptions have burst entirely through secondary rocks, nsisting of sandstone and conglomerate, with some thick ds of limestone. At the southern boundary of the volcanic untry, rocks of gneiss, mica slate and clay slate occur. ere are about fourteen distinct cones with craters, besides eral points whence lavas may have issued. The volcanic tter consists of scoriæ and lavas, which frequently put on e appearance of columnar basalt.

The extinct volcanoes in Hungary have also occupied the ention of geologists, and various notions were advanced specting their origin. But the most complete and satisfacry account of them has been given by Beudant.[†] There e five different places in Hungary in which extinct volnoes occur.

The first is the district of Schemnitz and Kremnitz, occu-

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[*] Geology, iii. 181. [†] Voyage en Hongrie, 3 vols. 4to. Paris, 1822.

pying an elliptical space of about twenty leagues in its greatest diameter, and fifteen in its smallest. The second is a smaller group on the south of the preceding one, constituting the mountains of Dregeley, near Gran, on the Danube. The third is the mountain group, known by the name of Matra, situated in the heart of Hungary, and east from the preceding groups. The fourth is a chain which commences at Tokai, and extends north to the heights of Eperies, in length from twenty-five to thirty leagues, and in breadth about five or six. The fifth or last region of extinct volcanoes in Hungary is that of Vihorlet to the east of the preceding, and connected with the trachytic mountains of Marmorosch, on the borders of Transylvania.

These several groups are quite unconnected with each other, and every particular mountain appears to have been separately formed, for their escarpments rarely correspond, so that they cannot be viewed as detached portions of one general bed cut away by the operation of subsequent causes. The lavas from these extinct volcanoes consist of trachyte, of which Beudant distinguishes and minutely describes five different varieties. These are trachyte, trachytic porphyry, pearlstone, millstone porphyry, and trachytic conglomerate.

Extinct volcanoes occur also in Transylvania, which have been described in considerable detail by Dr. Boué. Those in Styria have been described by Von Buch.*

In Italy a great number of tracts occur where volcanoes now extinct have once existed. Of these tracts an interesting account will be found in Dr. Daubeny's work on Volcanoes.† I shall satisfy myself here with barely enumerating the names of the principal districts. These are,

1. The Euganian hills, south of Padua, exhibiting a trachytic tract not unlike that of Hungary.

2. The Vicentin, north of Vicenza, partly trap, but also exhibiting volcanic rocks.

3. Monte Cimini, Monte Amiata, the former near Viterbo, and the latter near Radicofani.

4. The lagunes of Tuscany.

5. The neighbourhood of Rome. The Capitol, Mount Aventine, and Mount Celius, are capped with a volcanic rock, to which the Italian geologists have given the name of stonetuff, while the Mons Esquilinus, Mons Viminalis, Mons

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* Transactions of the Berlin Academy, 1818—21.

† P. 113, &c.

Quirinalis, and Mons Hincius, consist of earthy tuff. The rest of the formations of Rome consist of marl, sandstone, and travertin; the two former of which have been formed under he sea, and the latter in a fresh water lake.*

6. Rocca Monsina, south-west of Mola de Gaieta, near he river Garigliano, the ancient Liris.

7. The Ponza islands on the coast of Italy, opposite Terracina and Gaieta.†

8. Mount Vultur, near Melfi.

9. Lago di Ansanto, between Mount Vultur and Rocca Monsina.‡

10. Solfatara between Monte Nuovo and Puzzuoli, near Naples.

11. Lake Agnano and Grotto del Cane, the Lake Avernus.

12. Monte Barbara, the Gaurus of the ancients.

13. Islands of Procida and Ischia.

In the Grecian Archipelago abundant remains of extinct olcanoes occur. Santorino has been already enumerated mong the active volcanoes of the present day, because about e beginning of the last century an actual eruption took lace. The island of Milo is generally admitted to show nequivocal proofs of being an extinct volcano. The same emark applies to Cerigo and Lemnos.

Extinct volcanoes exist also on the western coast of Sarinia, for an account of which we are indebted to Captain myth. The volcanic matter has been deposited on tertiary eds, and the cones and lavas seem to be very fresh.

The Canary Islands, Madeira, the Cape de Verde Islands, nd the Azores, exhibit abundance of extinct volcanoes, for n account of which we refer the reader to Von Buch, Daueny, and Lyell.

The islands of Ascension, St. Helena, and Tristan d'Acunha, re extinct volcanoes.

The mountains of the Isle of France consist of extinct olcanic matter, and the same remark applies to a portion of he Isle de Bourbon, while in another portion of that island n active volcano exists.

It would be tedious to enumerate the numerous traces of

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* The reader will find an excellent account of the geological structure of Rome, chiefly by Von Buch, in Poggendorff's Annalen, xvi. 1.

† See Poulett Scrope, Annals of Philosophy (second series), viii. 65.

‡ This is the valley or lake of Amsanctus of Virgil, Æneis, lib. vii. l. 563.

extinct volcanoes which have been observed in Arabia, Pal tine, Syria, Asia Minor, and in the Andes of South Ameri where also abundance of active volcanoes exist. Indeed Humboldt's remark, that no mountain exists in Amer higher than 10,000 feet, which is not volcanic, be true, by the greatest portion of the Andes must be ranked am extinct volcanoes.

The matter ejected from volcanoes is usually called *la* when it has issued in a melted state, and been consolida either under the surface of the sea or by exposure to atmosphere. When detached stony fragments are eject which are afterwards cemented together, the rock thus for is called *tuff.* And when matter is ejected in the state powder or dust, it is called *ashes.*

Lava, by modern geologists, has been recognised as c sisting of two distinct substances, namely, *trachyte,* and *gre stone,* and *basalt.*

The name *trachyte** was applied by Hauy to a kind of p phyritic lava, having for its basis a paste of felspar. And term, of late years, chiefly in consequence of the writings Von Buch, has been generally adopted by geologists. T name is obviously derived from the harsh and rough aspect the lava to which it is applied.

Trachyte, as has been already observed, consists of a pa of felspar filled with crystals of glassy felspar, often crack It sometimes contains crystals of hornblende, mica, i pyrites, and specular iron ore. More rarely augite, and m netic, or titaniferous iron ores. Before the blowpipe it m into a *white* enamel. This is characteristic of trachyte. T felspar paste is often white, but not always so, having so times a deep or almost black colour.

The most minute account of trachyte hitherto given to world is by Beudant in his description of the extinct volcan of Hungary. Dr. Daubeny has given an excellent abri ment of this account in his work on Volcanoes.†

According to Beudant, there are five different varietie trachyte, which he distinguishes by the names of *trac proper, trachytic porphyry, pearlstone, millstone porphyry, trachytic conglomerate.*

Trachyte, properly so called, is distinguished by its p phyritic structure, by the scorified and cellular aspect wh

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* From τραχυς, *harsh.*

† Page 93.

it has a tendency to assume, by its harsh feel, and by the presence of crystals of glassy felspar, generally cracked, and sometimes passing into pumice. Crystals of mica and hornblende are often present; and all these crystals are either confusedly united without any cement, or by the intervention of a paste of felspar, sometimes compact and sometimes cellular. This paste is generally light coloured, though different shades of red and brown are sometimes communicated by iron, and there is one variety in which the paste is *black* and semivitreous, intermediate in its characters between pitchstone and basalt; but distinguished from both by melting before the blowpipe into a white enamel. Augite and titaniferous iron frequently occur in it, but olivine is very rarely, if ever, present.

Trachytic porphyry, is distinguished from the first variety by the absence of scorified substances. Neither hornblende, augite, nor titaniferous iron, enter into its composition; but quartz and chalcedony, which are wanting in the former, are commonly present in this species. According to Beudant, there are two varieties of trachytic porphyry, the one with and the other without quartz, and in both, specimens occur possessing a vesicular structure. Indeed the subspecies, which is without quartz, often passes into pumice. Many varieties of trachytic porphyry contain a number of very small globules, which seem to consist of melted felspar, having often in their centre a little crystal of quartz or mica. The assemblage of these globules, leaving minute cells between them, sometimes gives to the rock a scoriform appearance. The chalcedony often occurs in small geodes and sometimes intimately mixed with the paste in which the crystals are imbedded.

Pearlstone, is characterized by the vitreous aspect generally belonging to its component parts. Trachytic porphyry passes insensibly into it. Pearlstone, properly so called, and likewise obsidian and pitchstone belong to this variety. Pearlstone occurs usually in Hungary, while obsidian, as we learn from Sir George Mackenzie, is common in the Iceland lavas. Pearlstone, in its simplest form, presents an assemblage of globules, from the size of a nut to that of a grain of sand, which have usually a pearly lustre and scaly aspect, and are set as it were one upon another, without any substance intervening.

From this, which is the most characteristic variety, the rock passes through a number of gradations. In some the globules are destitute of lustre, and become more and more minute till they entirely disappear, and the whole mass puts on a stony appearance. Sometimes the pearlstone passes into pitchstone or obsidian. Sometimes globules consisting of felspar occur in the rock, which are either compact or radiated from the centre to the circumference, and these are sometimes so numerous that the whole mass is composed of them. All these varieties occasionally present a cellular, porous, spongy, and fibrous aspect, and pass into pumice.

The *millstone trachyte* is distinguished by its hardness and cellularity, qualities which have caused it to be employed all over Hungary for millstones. Hence the name given to it by Beudant. It abounds in quartz, or at least in some of the modifications of silica; and puts on either the appearance of hornstone or of claystone porphyry. The paste is always dull and coarse looking. Its colours vary from brick-red to greenish-yellow; its fracture is generally earthy, and its hardness variable, but usually considerable. It contains crystals of quartz, of felspar, lamellar, and sometimes glassy, and of black mica imbedded. Jasper and hornstone also occur in nests, or in small contemporaneous veins very abundantly disseminated, and siliceous infiltrations posterior to the formation of the rock, seem likewise to occur among the cells, which are every where distributed. By the assistance of a glass, many little globules, analogous to those in the pearlstone, seemingly of a felspathic nature, may be discovered. These, when broken, are found to contain in their centre a little crystal of quartz, or a speck of some siliceous substance. These globules in some cases compose the whole substance of the paste, in others they are held together by a sort of hardened clay, which here and there resembles porcelain jasper.

The fifth variety, called by Beudant *trachytic conglomerate*, consists of those heaps of pumice and other loose materials which occur agglutinated together on the slopes and at the base of the rocks belonging to the four preceding classes. Although the prevailing constituent is pumice, every rock existing in the neighbouring hills is met with among the fragments. These vary extremely in size as well as in the mode of aggregation. The cement which unites them is often of porphyritic character, hardly distinguishable from the fragments themselves. Crystals of felspar, mica, and hornblende and sometimes grains of titaniferous iron, are diffused through it, or it is coloured red by the peroxide of iron.

fragments of pumice are united together, either im-
ely or by the intervention of a paste of a vitreous cha-
esembling obsidian, into which the pumice passes insen-
Sometimes the whole rock is decomposed and con-
into an earthy matter, similar to the *trass* of the Eisel
es, or the *tripoli* of those in Auvergne. By a still
alteration, the mineral called *alumstone* is formed, which
loyed in the manufactory of alum, both in Hungary
the Roman states at Tolfa.*

ough trachyte be one of the commonest appearances
lavas put on, it is not the only one. Several of the
of lava from Vesuvius, as those of 1760 and 1794,
le *basalt* exactly in colour, fracture, hardness, and
. I have specimens of lava from the same volcano,
cannot be distinguished from ordinary *greenstone*, being
at rock, composed of grains or crystals of hornblende
spar. Amygdaloidal rocks are not wanting among these
and the vast number of crystallized minerals found in
cks has been long known to mineralogists.

or *Tufo*, is an Italian name for a variety of volcanic
f an earthy texture, seldom very compact, and composed
agglutination of fragments of scoriæ and loose matter
from a volcano. Tuff may be studied to great advan-
Rome and its environs. What occurs in that locality
en divided into *stone tuff* and *granular tuff*.

e tuff constitutes the summit of the Tarpeian rock of
Aventine and Mount Celius. Its colour is reddish-
with orange streaks, proceeding from interspersed
of pumice. It is earthy and almost conchoidal in its
e, and hard enough to be employed as a building stone.
tains white mealy leucites, plates of brown mica, crys-

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chyte being in fact a compound rock, little advantage can be
d to result from its analysis. The following table exhibits the ana-
two varieties of it from Puy de Dôme and Pertuis, by Berthier.†

Silica,	65·5	61·0
Alumina,	20·0	19·2
Potash,	9·1	11·5
Lime,	2·2	—
Magnesia,	—	1·6
Oxide of iron,	3·0	4·2
Water,	—	2·0
	99·8	99·5

[†] Ann. de Chim. et de Phys. xvii. 35.

tals of black and green pyroxene, and very rarely small grain of felspar. Here and there rounded and angular fragment of limestone occur in it. Sometimes the grains of which it i composed are so small, that it appears a homogeneous mass excepting that fine scales of mica may still be distinguishe in it.

The stone tuff occurs at Rome, in beds from 1 to 6 fe thick, penetrated by long, vertical, and sloping clefts, form probably during the drying of the mass. The fine granul variety, in consequence of the position of the scales of mi has commonly a slaty structure. The ancient Elvacæ a chiefly composed of stone tuff, probably quarried from t Capitol. It occurs also in the walls of the theatre of Marc lus and in other buildings.

Granular tuff, differs much in its appearance from sto tuff. It has a blackish-brown or yellowish-brown colour, light, friable, and is composed of thick grains slightly agglutinated together, intermixed with scales of mealy leucite fragments of augite, scales of mica, and occasionally pieces o blackish-grey lava. Sometimes it puts on the appearance o a porous pumice lava, to which the Italians gave the name o *lapillo*. The degree of hardness, and the colour of granular tuff vary very much, according to the degree of decomposition which it has undergone. Sometimes it has quite the characte of lapillo, being only a little less dry and meagre to the feel or it is exceedingly friable, loses its porous texture, an assumes an earthy aspect. When much acted on by rai water it assumes the aspect of clay, which adheres to the tongu and becomes plastic when moistened. In such cases the leucit disappears, but the augite and mica may still be distinguished It is of this earth that bricks are made at Velletri, at the foo of Mount Artemisio. At St. Agatha in Campania it is employed for making stoneware vessels.

When this tuff is decomposed in a very great degree it constitutes a peculiar variety, to which Brocchi has given th name of *earthy tuff, tufa terrosa*. It is of a yellow colour extremely light, and so friable that it readily crumbles to dust which absorbs water with a hissing noise and gives out strong earthy smell. This tuff constitutes the whole o Mounts Pincius, Quirinalis, Viminalis, Esquilinus, and th greatest part of Mount Celius and Aventinus.

What is called *ashes* consists of a very fine powder, which i emitted frequently during volcanic eruptions in immense quantities, and sometimes it is carried by the wind to an immense distance. I have a quantity of *ashes* which covered a ship at the distance of two hundred miles, during the great eruption in St. Vincents, in the year 1812. The nature of these ashes is not always the same; it doubtless varies according to the nature of the rocks in which the volcanic energy exists.

Volcanic eruptions most commonly proceed from the summits of conical mountains, composed entirely of lava, and therefore formed by successive eruptions. Hence, at the commencement, the probability is that no mountain existed, but that the eruption originated from level ground. The indications of an approaching eruption are earthquakes, frequently very severe, subterraneous noises, and violent bellowings. And in the neighbourhood of Vesuvius, an approaching eruption is always indicated by the wells becoming dry. Soon after, the smoke, which issues continually from the crater of a volcano, increases in intensity, and rises in the form of a vertical column, the upper part of which, in consequence of its weight, spreads out into a top, which has been compared to the head of a gigantic pine-tree. This tree agitated by the wind, assumes the form of a thick cloud, which transported to a great distance, leaves here and there large masses of smoke.

The progress of the combustion is announced by the projection of ashes, scoriæ, and red hot stones, which rise to a great height and fall back again either into the crater or on the sides of the mountain. At last a quantity of melted lava rises to the top of the crater, and flows down the sides of the mountain like a melted metal. Before the eruption, the lava fills the crater, having a vast quantity of scoriæ floating on its surface, and as it alternately rises and falls, the scoriæ appear and disappear at intervals.

The lava at last passes over the brim of the crater, runs down the side of the mountain to the bottom; there it spreads out assuming a progressive motion. In general, it flows from under a kind of crust formed by the portion at the surface becoming consolidated. As it advances, it destroys and envelopes every thing which it meets with on its passage, passes over the obstacles which it cannot remove, spreads over the cultivated fields, frequently for leagues in extent, and carries desolation and destruction wherever it goes.

When the lava confined in the crater is too compact and heavy to make its way to the summit, one or more ruptures frequently take place on the sides of the mountain, whence it issues with phenomena similar to those already described.

Nothing approaching to regularity has been observed in the intervals between the eruptions of the same volcano. Ætna and Vesuvius are the only two with whose eruptions, for a long series of ages, we are acquainted. From the description of Vesuvius given us by the ancients, and from the observations of Diodorus Siculus, there can be no doubt that it had been in an active volcanic state at a very remote period. And Vitruvius, when speaking of the Puzzolana near Naples, which he supposes to have been formed by heat, notices a tradition, that Vesuvius also in former times emitted flames.* But it had remained quiet for so long a period, that no idea of its volcanic nature seems to have been entertained by the Romans previous to the tremendous eruption of the year 79, which proved fatal to the elder Pliny, and which has been so minutely described by the younger Pliny.

The earliest eruption of Mount Ætna is that mentioned by Thucydides, which must have taken place about 480 years before the commencement of the Christian era. The following table exhibits the different eruptions of these two mountains which have taken place since these remote periods.†

Ætna.	*Vesuvius.*
B.C.	
480, or thereabouts.	
427	
396	
185 eruptions between the Eolian islands, according to Pliny, 200 B.C.	
140	
135	
126 or 125	
	91 eruptions in Ischia.
56	
45 or 44	
A.D.	
40	

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* See Daubeny on Volcanoes, p. 149.

† The table is taken from Dr. Daubeny on Volcanoes, p. 214, who extracted it with some few additions, from Hoff's *Geschichte der Veranderungen der Erdoberflache.*

Ætna.	*Vesuvius.*
	A.D.
	79
	203
	512
	685
	983
	993
	1036
	1049
	1138, or 1139
ary 4	
98 and 1250	
1198, the Solfatara inflamed.	
1302, eruption of Epomeo in Ischia.	
	1306
28	
mber 9	
mber	
	1500
till 1537	
September, formation of Monte Nuovo near Puzzuoli.	
2 } Continuance of small eruptions during this interval.	
	1631, December 16
ary 22	
mber	
	1660, July
8	

Ætna.	*Vesuvius.*
A.D.	A.D.
1682, December	1682 August 12
1688	
1689, March 14	
1694, March to December, (only ashes)	1694, March 12, with fee recurrence of action 1698
	1701, July 2 till 15
1702, March 8	
	1707, May 20 till August
	1712 Feb. 18, eruption c tinued till the follow year
	1717, June 6, continued before
1723, November, beginning of the month	
	1727, July 26
	1730, February 27
1735, October, beginning of the month	
	1737, May 14
1747, Sept., volcanic action continued for some years	
	1751, October 25
	1754, December 2
1755, March 2	
1759	
	1760, December 23
1763, June 19	
1766, April 27	1766, March 25
	1767, October 23
	1770
	1778, September 22
	1779, August 3
1780, May 18	
1781, April 24	
	1783, August 18
	1784, October 12 and D
	1786, October 31
1787, July 28	1787, December 21
	1788, July 19

Ætna.	*Vesuvius.*
	A.D.
	1789, September 6
rch	
	1794, June 15
ne	
ne	1799, February
bruary 27	
	1804, Aug. 12 and Nov. 22
	1805, July
	1806, May
rch 27	
	1809, December 10
	1811, October 12
tober 28	
	1811, December 31
	1813, May to December
	1817, December 22 to 26
	1818
	1819, April 17
y 29	
	1819, November 25
	1822, February 13 to 24
	1822, October 22
	1828, March 14 to 22
y 20	
	1834
	1835, March 13

espect to the origin of volcanoes, no theory even o the name of plausible has been hitherto offered. scribed the commencement of the combustion to the water upon iron pyrites, or upon a mixture of sul- iron. But the phenomena of volcanoes are utterly nt with such an hypothesis. It is true that sulphur frequently emitted from the craters of volcanoes, hat some combination of it exists under the earth at where the volcanic fire rages. But the evolution of iac, boracic acid, and of prodigious quantities of cid, shows that the combustible materials are differ- ron and sulphur.

c's hypothesis is merely a modification of that of He suggests that volcanoes may arise from masses of petroleum collected in underground caverns, and set on fire by some third substance. In his opinion, certain combinations of phosphorus, or even of sulphuric acid, may occasion the commencement of the combustion. And he considers the conflagrations which occasionally occur in the coal mines, as proving that such substances do in fact occasionally take fire. But the vastness of the phenomena, and the very great depth at which the burning matter is situated, are quite incompatible with such an origin.

Werner's hypothesis, ascribing volcanoes to the burning of coal, is not reconcileable to facts known respecting the great depth of the volcanic foci below the surface of the ground; though the nature of the gaseous matters given out from volcanoes rather favours the notion that carbon, in some state or other, is one of the substances subjected to combustion. Dr. Daubeny condensed a portion of the vapour given off round the crater of the Island of Volcano, and found it to contain sulphurous acid. The vapour from the Solfatara of Puzzuoli contained sulphuretted hydrogen. The vapour condensed from the spiracles on the exterior of the crater of Ætna consisted of water, with a trace merely of muriatic acid. M. Boussingault has examined the nature of the elastic fluids disengaged from the volcanoes in South America, situated near the equator, and found them the same in all: namely, vapour of water, carbonic acid gas and sulphuretted hydrogen. Sometimes azotic gas and sulphurous acid gas occur; but these two gases are accidental. The azotic gas comes from a mixture of common air, and the sulphurous acid from the combustion of the vapour of sulphur which abounds in all volcanoes. The following table shows the names of the volcanoes, their height above the sea, and their latitude and longitude from Greenwich:—

Names of Volcanoes.	Height above the Sea. Feet.	Latitude.	Longitude.
Tolima, . . .	18,045	4° 35′ N.	76° 30′ 40″ W.
Azufral of Quindiù,	At the base of Tolima.		
Puracé, . . .	17,008	2° 20′ N.	78° 50′ 40″ W.
Pasto, ...	13,452	1° N.	79° 34′ 40″ W.
Tuquères, . . .	12,821	0°	
Cumbal, . . .	15,620	0°	

The gaseous matter issuing out of Tolima contained 0·14 of carbonic acid gas. It contained about $\frac{1}{1000}$th of its volume of sulphuretted hydrogen. No other acid except sulphuretted hydrogen could be detected.

The gaseous matter issuing from the Soufrière of Quindiù onsisted of 95 per cent. of carbonic acid gas, and only 5 per ent. of common air. The sulphuretted hydrogen amounted about $\frac{1}{1000}$th part.

The gas from Puracé contained 85 per cent. of carbonic id gas, and 15 per cent. of common air, with a trace of lphuretted hydrogen.

The constitution of the gaseous matter from the other lcanoes was found quite similar to that from the three lcanic sources just mentioned.*

From these experiments, there can be no doubt that carbonic id is evolved in considerable quantity, at least from the lcanoes in South America, which are situated in the neighurhood of the equator. Another constant ingredient in the astic matter given out by volcanoes is vapour of water. his seems to be a constant and even essential constituent. oubtless the volcanic force which produces earthquakes, mbling noise, eruptions of lava, and heaving up of the solid rtions of the crust of the earth, owes its energy, at least to a nsiderable extent, to the high temperature to which the ater in contact with the burning lava is raised. It has been general opinion, that no volcano can exist in an active state less it be situated in the neighbourhood of water. Most of e volcanoes with which we are familiar are not far from the a; but if the report respecting the existence of two active lcanoes in central Tartary be true, it is obvious that a aritime situation cannot be essential, though it is not unlikely at these inland volcanoes may be near a lake, which might swer all the purposes of a proximity to the sea. I am posed to ascribe the energy of volcanoes in a great measure the action of steam, and so far to admit that the presence water is essential to that energy.

In the year 1700, Lemery published a *Theory of Volcanoes*, ich was long considered satisfactory. He mixed together ual quantities of iron filings and sulphur, moistened with ter. Fifty pounds of this mixture contained in a large t was put into a hole in the garden, covered with a linen th, and then with earth to the height of about a foot. ter an interval of eight or nine hours the earth was observed

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* Ann. de Chim. et de Phys. lii. 5.

to swell, to become hot, and to crack; then sulphurous and hot vapours issued from it; finally flames made their appearance, which enlarged the opening, and scattered round the place a yellow and black vapour.* From this experiment Lemery concluded that volcanoes were owing to the heat produced by the action of moist sulphur and iron on each other. In such an action the water is decomposed, and the sulphur acidified, and the iron oxidized. Sulphuretted hydrogen would be emitted, and perhaps also vapour of water; but we would look in vain for the source of the carbonic acid, of the muriatic acid, and of the sal ammoniac, which are so frequently observed to accompany volcanic eruptions.

Sir H. Davy, after his discovery of the metallic nature of potassium and sodium, and of the great combustibility of these bodies, conceived that the phenomena of volcanoes might be accounted for by supposing that the internal parts of the earth are composed of potassium and sodium, and that violent combustions are produced when water comes in contact with these very combustible metals; and Gay-Lussac extended this plausible explanation still farther, by supposing that not only potassium and sodium, but calcium, magnesium, aluminum, and silicon, may all exist in the interior parts of the earth, and may also occasion violent combustions when they come in contact with water; but neither the specific gravity of the earth, nor the nature of the elastic fluids emitted by volcanoes, will permit us to adopt this hypothesis. We are too imperfectly acquainted with the phenomena of volcanoes, and with the nature of the gaseous matters which they exhale, to be in a condition to form even a plausible hypothesis respecting the origin and continuance of these very formidable objects.

CHAP. XVIII.

OF THE ELEVATION OF MOUNTAINS.

When mountain chains are composed of stratified rocks, as is frequently the case, these strata are usually very much inclined, and sometimes almost vertical. This has led modern geologists to adopt an opinion first advanced by Dr. Hutton, and

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* Histoire de l'Académie Royale. Mémoires, 1700, p. 103.

usly supported by Mr. Playfair, that these strata were
ly horizontal, and that they owe their inclined or
position to their having been elevated by a force
rom below. Against the sides of these inclined strata
ual to find other stratified rocks abutting, and which
a horizontal position. It is difficult to avoid concluding
ese phenomena that the mountain chains so circum-
were elevated and brought into their present position
the horizontal beds abutting against them had been
ed. Thus, for example, if a range of mountains com-
f the different beds belonging to the oolitic formation,
in an inclined or vertical position, be abutted against
zontal beds of the green sand or chalk formations, it is
that the oolitic mountains were elevated before the
ion of the green sand or chalk. If mountains composed
ed beds of red sandstone formation be abutted against
zontal beds of the oolitic formation, it is concluded that
sandstone mountains were elevated before the deposi-
the oolitic beds. Humboldt, Von Buch and some
of our most eminent geologists, have examined the
t mountain ranges of Europe, and have concluded that
ay be separated into three or four different systems,
ished by the nature of their constituents, and by the
s of their component parts to any assumed meridian.
lie de Beaumont has carried his generalization much
and has concluded that each of these great systems of
in chains, marked on the map of Europe by given
lines of direction, has also a given period of elevation,
and defined by direct geological observation. All
hains which have been elevated at the same time are
to each other. Hence by determining the parallelism
ns we ascertain those which were elevated together;
he nature of the horizontal beds leaning against these
strata, enables us to determine the relative age of the
n of each of these chains, and thus to deduce the order
h these mountain chains were raised into their present
. It will be proper to give a view of these different
of mountain chains, which amount to twelve in
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he oldest mountain chains with which we are at present
ted are those in the south of Scotland, the north-west
land, Wales and Cornwall. The lake mountains in
rland have been investigated with much skill and in-

dustry by Professor Sedgwick; he has shown that they run from N. E. ¼ E. to S. W. ¼ W. They consist of slate rocks, and obviously lie under the coal beds which abut against their sides. Sedgwick has shown that they were elevated before or during the period of the deposition of the old red sandstone. Other circumstances lead to the conclusion that they were elevated before the deposition of the newest of the transition, namely, the Trilobite limestone of Dudley and Tortsworth. The chain of mountains running, in Scotland, from St. Abb's Head to the Mull of Galloway, or rather to Loch Ryan, is parallel to the Westmoreland chain and of the sam age. The greywacke chain in the Isle of Man, and the chain of slate rocks in Anglesea and North Wales, and even i Cornwall, run in a parallel direction, and are, doubtless, o the same period. On the continent the mountain chains o Hundsrück, of the Eifel, Nassau and several portions of th Vosges have the same direction and are of the same age.

2. The *second system* consists of the Belchen mountains i the Vosges and the Hügel in Calvados. It would appear fro a careful examination of the Westmoreland mountains th they were elevated before the deposition of the newer mem bers of the slaty series. The transition mountains in th south of Ireland, described by Weaver, appear to have bee elevated at a somewhat later period than those in Westmor land and Wales and the south of Scotland. Those of Hüge in the Bocage, and those constituting the south-east corner the Vosges appear to belong to the same era with those in th south of Ireland. The direction of these mountain chains north-east and south-west.

3. The *third mountain chain* in the order of time is th which runs from the border of Scotland through the north England, as far as Derbyshire and Yorkshire. This mou tain chain, distinguished by the Romans by the name of t Penine Alps, consists of stratified rocks belonging to the low part of the series of the coal beds, and is surrounded in almo every direction by the great coal formation of the north England. This mountain chain runs very nearly due nor and south, inclining a little, however, to the north-west an south-east direction.

It is not probable that this mountain chain is isolated. M Elie de Beaumont is of opinion that the problematical rock which cut through the coal formation of Shrewsbury and Coa brookedale, the Malvern hills and the rocks which travers the coal formation of Bristol in a north and south direction belong to the same period.

4. The *fourth system of mountain chains* constitutes the mountains of South Wales and of the Netherlands. From the neighbourhood of Aix la Chapelle to the small islands in the Bay of St. Bride in Pembrokeshire, constituting a tract of nearly five hundred miles in length, we find the different beds of the coal formation in every place not covered by some of the newer formations. There are however parts, as at Lüttich, Mons, Valenciennes, Norotingen (in the Boulognais) and the foot of the Mendip hills, where the most wonderful contortions present themselves to our view. In a great part of this tract the same beds appear, which nowhere reach to any great height, and are covered with newer formations lying in a horizontal position. The direction of this low chain is nearly west by north; it consists chiefly of members of the coal formation. In the neighbourhood of Bristol the magnesian conglomerate covers, in a horizontal position, the inclined beds of the coal formation. At Saarbruck the sandstone of the Vosges is found in a similar position. Hence the elevation of the beds of this chain must have preceded the deposition of the magnesian conglomerate of Bristol, and the sandstone of the Vosges.

5. To the fifth system Von Buch has given the name of the *system of the Rhine.* It consists of two symmetrical mountain chains, the one constituting the Vosges mountains, and the other those in the Black Forest. The Rhine flows between these ranges, and they enclose the greatest part of the province of Alsace. They consist partly of the sandstone of the Vosges, and exhibit great rifts and dislocations, the beds having been forced out of their original position. The elevation of these mountain chains must have preceded the deposition of the new red sandstone, the muschelkalk and the keuper, which fill up the interval between them, constituting the flat country of Alsace.

6. The *sixth system* consists of elevations which run in a north-westerly and south-easterly direction, and which were elevated between the time of the deposition of the keuper, which belongs to the new red sandstone formation, and the Luxemburg sandstone, which belongs to the oolitic formation.

The great oolitic formation, known on the continent partly by the name of Jura limestone, and partly by that of roestone and oolite, from the granular structure of many of its beds, was deposited, originally, in almost horizontal beds. It follows the contour of the sixth class of mountain chains in which the variegated sandstone, the muschelkalk and the keuper, as well as all older beds, are obviously elevated out of their original position. The beds of the Jura formation, on the contrary, stretch out in a horizontal position till they abut against the acclivity of the hills belonging to the sixth class, and even cover the upper parts of their inclined beds.

In the interior parts of France, at Avallon and Autun, we see hills running from the north-west to the south-east, and consisting of granite rocks, of inclined beds of the coal formation, and of arkose beds of the same age with the keuper. Similar hills occur in Brittany and in La Vendée; in Germany, constituting the mountains between Bohemia and Bavaria, the Thuringerwalde and various other ranges of hills in Saxony and Westphalia, very well laid down in Hoffmann's fine map of the north-west of Germany. This sixth class of mountain chains has obviously been elevated between the time of the deposition of the keuper and that of the Luxemburg sandstone and lias.

7. Many appearances show that in the interval between the periods of rest which correspond with the deposition of the Jura formation and that of the green sand a sudden and important change in the nature of the deposits took place; this sudden alteration appears to correspond with the elevation of the beds of a system of mountains under which that of the Côte d'Or in Burgundy, of Mont Pilas in Forez, of the Cevennes, the heights of Larmac, and even the Erzegebirge, between Saxony and Bohemia, may be reckoned.

The Erzegebirge, the Côte d'Or, the Pilas and the Cevennes belong to a set of elevated beds which have a north-east and south-west direction, stretching from the mouth of the Elbe to the canal of Languedoc. A careful examination of these mountains leads to the opinion that they were elevated at once by the same convulsion of nature. In France the beds of the Jura formation correspond with the direction of these mountain chains, while in Saxony the beds of green sand which abut against the sides of the mountains have a horizontal position. Hence it follows that the Erzegebirge were elevated before the deposition of the green sand, while the mountains of the Côte d'Or must have been elevated after the deposition of the Jura formation. And if all these mountains were elevated at one and the same time, it is obvious that this elevation must have taken place between the deposition of the Jura formation and that of the green sand and chalk.

8. *System of Mont Viso.* The French Alps and the south-west end of Jura, from Antibes and Nizza to Pont d'Ain and Lons le Saulnier, exhibit a range of mountains and elevations running nearly in a north north-west and south south-east direction, and in which the older beds of the green sand formation and the chalk, as well as those of the Jura formation, have an inclined position. The primary mountain pyramid of Mont Viso is traversed by mighty dislocations, obviously produced at the time that these chains of mountains were elevated. At the foot of the eastern crest of Devolny, which exhibits elevated beds of green sand and chalk, there exist, near the Col de Bayard, north from Gap, horizontal beds of the same formation, distinguished from the older beds by the presence of a great number of nummulites, cerithia, ampullariæ and other shells, which must have been deposited long before the appearance of any of the tertiary formations. It is evident that the rocks, constituting the Mont Viso system, must have been elevated in the interval between the deposition of the oldest and newest of the green sand and chalk beds.

9. *System of the Pyrenees.* The mountain chain of the Pyrenees runs from Cape Ortegal in Gallicia, to Cape Cross in Catalonia, from the west north-west to east south-east. From the observations of several geologists, it appears that tertiary formations stretch themselves horizontally to the foot of these mountains without entering into their composition, as is the case with the chalk. It follows from this, that the Pyrenees acquired their present position, with reference to the neighbouring portions of the earth's surface, between the period of the deposition of the greensand and chalk, which according to the observations of M. Dufrenoy are found on the very summits of these mountains, and the deposition of the tertiary beds of different ages, which that geologist traced in a horizontal position to the foot of the mountains.

The mountain chain of the Apennines is parallel to that of the Pyrenees. We allude to the mountains between Modena and Florence, and between Bari and Tarentum. And the age of these mountains seems to be the same as that of the Pyrenees. The Julian Alps between Venice and Hungary, as likewise a part of the mountains of Croatia, Dalmatia, Bosnia, and even of Greece, seem to belong to the same era.

It deserves attention, that a line drawn from the neighbourhood of London to the mouth of the Danube constitutes the southern boundary of an immense tract of flat country, which is almost every where covered with new formations. This line is nearly parallel to the mountain chains of the Pyrenees and the Apennines. It perhaps marks the southern border of an extensive sea, which at the time of the deposition of the tertiary beds covered a great portion of Europe. Towards the south it was bounded by a continent, divided by various bays, of which the mountain chain of the Pyrenees constituted the highest summit. The fragments of tertiary beds which have been deposited in the hollows of this continent often run in lines parallel to the direction of the mountain chain of the Pyrenees.

M. Elie de Beaumont is of opinion that the elevation of the hills in the neighbourhood of Paris and London, and in the Isle of Wight, took place at the same period with that of the Pyrenees.

10. *System of Corsica and Sardinia.* The tertiary beds do not proceed to any great extent without interruptions. Various such may be observed, all of which correspond with a range of mountainous heights running in a north and south direction. M. Elie de Beaumont has concluded, from a careful examination of the tertiary formations in France, that they are divisible into two series; one of which, consisting of plastic clay, coarse limestone, and the whole gypsum beds, together with the uppermost marl, scarcely extends farther south than Paris; while the other, represented in the north by the sandstone of Fontainbleau, the upper fresh-water formation, and the *fahluns* of Touraine, constitutes almost the whole tertiary formations in the south of France and in Switzerland, especially the brown coal beds at Fuveau and Kopfnach. The sandstone of Fontainbleau, lying on the marl of the gypsum formation, constitutes the first bed of this system, just as the sandstone of the lias lying on the Keuper constitutes the first bed of the Jura formation. The first stands in the same relation to the Arkose of Auvergne that the second does to the Arkose of the Jura formation at Avallon.

These two tertiary formations are distinguished by the fossil remains of large animals which they contain. The bones of Anoplotherium and Palæotherium found at Montmartre characterize the first, while other species of Palæotherium, almost the whole species of the genus Lophiodon, the whole genus of Anthracotherium, and the oldest species of the genera mastodon, rhinoceros, hippopotamus, castor, &c. characterize the second.

It is the line dividing these two tertiary formations from each other, which constitutes the class of mountains which M. Elie de Beaumont considers as constituting his tenth system. These mountains run in a northerly and southerly direction. It is the beds of the second set of tertiary deposits that constitute the contour of these mountains.

To this system belong the heights of the Loire and the Allier, with their continuation by Clermont, and the volcanic rocks of Monts Dômes, so well described by M. Ramond. The broad valleys between these ranges of mountains constitute the fresh-water formations of Limagne, Auvergne, and the large valley of the Loire.

The valley of the Rhone runs likewise from north to south, and is to a certain level covered with tertiary formations, the lower beds of which have much resemblance to those of Auvergne, and are obviously fresh-water deposits, while the upper beds belong to a sea-water formation. Here the regularity of the tertiary formations is destroyed by the upheaving which the surface of the earth has undergone, in consequence of the elevation of the western Alps, and of the principal chain of the Alps.

The mountains in Corsica and Sardinia run in the same lirection, and are of the same age. Mountains having the ame direction occur also in the Apennines and in Istria, in Iungary, Servia, Macedonia, and Thessaly. A chain of the ime kind seems to constitute the east coast of the Morea, id to appear in the island of Candia. The range of Mount ebanon, and those heights which run along the Dead Sea the borders of the Red Sea appear to belong to the same a, as may be concluded from the late observations of Botti.

11. *System of the Western Alps.* The elevation of the estern chain of the Alps is manifestly subsequent to the position of that tertiary formation, to which the French ologists have given the name of *molasse coquillière.* This rmation lies near Lyons in horizontal beds, and covers the imary rocks of Forez. But as it approaches the Alps it comes elevated, and at Rigi reaches a height of 6152 feet ove the level of the sea. Messrs. Sedgwick and Murchison served that the chalk and the tertiary beds, which at the ot of the Bohemian mountains have a horizontal position, come elevated on the other side of the Danube, and appear

at considerable heights in the Alps. Messrs. Murchison an Lyell have observed that the tertiary formations in the Itali side of the Alps have assumed a similar position. An Messrs. Brongniart and Buckland observed similar formatio in the Diablerets elevated to the limit of perpetual snow.

Though we are accustomed to consider the Alps as const tuting a single and continued chain of mountains, there c be no doubt that in reality they constitute more than o system, differing from each other both in age and in t direction of the beds. Throughout almost their whole exte and especially towards their eastern extremity, we meet w traces of several small chains which have the direction of t Pyrenees, and like them have been elevated before the depo tion of the tertiary beds. But these ancient displaceme are often covered by newer formations. The highest a most complicated part of the Alps, the portion in the neig bourhood of Mont Blanc, Mont Rosa, and the Finsteraarho consists principally in the crossing of two of these new systems, which meet at an angle of from 45° to 50°, and whi are distinguished from the Pyreneo-Apennine system, both b their direction and their age. In consequence of the tw systems crossing each other, they form at the summit of Mo Blanc a knee. From Austria to Wallis, the direction of th beds is E. ¼ N. E. to W. ¼ S. W. But at Mont Blanc the suddenly assume the direction N.N.E. to S.S.W.

In the innermost system of the mountain chain, of whic the Western Alps are mostly composed, we perceive no new beds than those of chalk, while these chains rise from a botto which had already assumed an elevated position immediate before and immediately after the deposition of the chal that is to say, at the time of the elevation of Mont Viso a the Pyrenees. It is obvious from the appearance and positio of the beds constituting the Western Alps, and of the form tions resting on them, that they were elevated after th deposition of the newest tertiary formations in the neighbou hood.

The beds of *molasse coquillière* are found upon the hill Superga, near Turin, and on the west side of the mounta of the great Chartreuse, near Grenoble. Many other simil examples might be given, showing clearly that the Weste Alps have been elevated after the deposition of the *molass coquillière*.

12. *System of the high chain of the Alps, from Wallis t*

Austria. The valley of the Isère, of the Rhone, of the Soane, and the Durance, exhibit two very different alluvial formations, which are well distinguished from each other by their position and their characters.

The inundations which brought the materials of the first of these formations, appear to have proceeded from the fresh water lakes which once covered the northern side of the departments of the Isère, and of other places situated in the departments of the Lower Alps. The materials of the second formation, on the other hand, appear to have been deposited from streams which rushed with violence into the Mediterranean. It is usually called a diluvial stream, though it must have existed before the creation of man, but when other animals which it destroyed existed on the earth. M. Elie de Beaumont is of opinion, that it was occasioned by the sudden melting of the snow on the summits of the western Alps, at the time when the elevation of the principal Alpine chain took place. M. de Beaumont deduces from a long series of observations, that the principal Alpine chain was elevated after the deposition of the former of these diluvial formations, and before that of the latter. This he deduces from the horizontality of the latter and the inclined position of the former, when they are in contact with the beds of this Alpine chain.

Such is a short outline of the opinions entertained by M. Elie de Beaumont, respecting the relative ages of the different mountain chains which occur in Europe; but sufficient, we trust, to give our readers an idea of his general views. There can be little hesitation in admitting, that the method of induction pursued is unexceptionable, and that, provided the observations on which this induction is founded be accurate, he has made out his positions, so far as the relative ages of the different mountain chains are concerned. His opinion, that all of these mountain chains which are parallel to each other, were raised at once and with violence, does not seem to me to rest upon such unexceptionable evidence. The induction proves only, that each mountain chain must have been elevated after the deposition of those beds that rest against it in a vertical or inclined position, and before the deposition of those beds which abut against it in a horizontal position; but it gives us no information respecting the time which may have elapsed between the deposition of the former and the latter. M. de Beaumont, not satisfied with the European chains, has applied his opinions to the elevation of mountains in general, and has indulged in a series of such bold conjectures, that in a work like this, the object of which is to lay facts rather than conjectures or speculations before the reader, we hesitate about venturing to pursue the subject farther. At the same time, we strongly recommend M. de Beaumont's views to the attention of all practical geologists in their future observations.*

CHAP. XIX.

CONCLUSIONS.

THUS we have taken a view of the structure of the whole surface of the earth, so far as we are acquainted with it. Before quitting the subject, it will be worth while to take a short review of the principal facts, in order to discover what theoretical conclusions respecting the alterations to which the earth has been subjected since its original formation, they may enable us to draw.

1. The first thing that strikes us is, that all the formations of which the crust of the earth is composed, from the very highest and most recent, down to the very lowest to which we have access, are composed of regular beds lying over each other, sometimes exceedingly thin, sometimes of enormous thickness; but proceeding unvaried for a considerable way. Such regular stratification can be accounted for only by the action of the sea. It follows, therefore, that the whole crust of the earth hitherto examined, is composed of strata, which have been arranged in beds under the surface of the ocean. Consequently the surface of the earth, and its crust to a certain depth, presents no rocks or formations identical with those that existed at the original formation of it. The whole has been disintegrated and new modelled under the waters of the ocean.

2. Besides the stratified rocks, constituting so great a proportion of the earth's crust, there exists another set of rocks which exhibit no traces of stratification, but which exhibit very strong indications of having been pushed upwards from below in a state of fusion, and of having afterwards

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* The reader will find a short but excellent view of the whole subject, in a letter by M. Elie de Beaumont to M. Von Humboldt, in Poggendorff's Annalen, vol. xxv. p. 1.

solidified and crystallized more or less slowly. These are granite, porphyry, serpentine, the trap rocks, and lavas. These rocks were not all formed at once, nor under the same circumstances. They seem to have been protruded occasionally at all times from the deposition of the gneiss, mica slate, and clay slate formations, to that of the chalk, and even of the fresh water formation—a period of immense extent, and to which, indeed, we have no means of assigning any limits.

The formation and protrusion of these plutonic rocks may have been connected with the solidification and elevation of the stratified rocks. This solidification and elevation must have taken place successively, and must have occupied a very long period, to which, like the last, we have no means of assigning any limits.

3. The gneiss, mica slate, and clay slate beds, contain no remains of vegetables or animals, though such remains are to be found in all the other formations, except the plutonic. Either no animals or plants existed on the earth at the time when these beds were deposited at the bottom of the sea; or if they did, and if their remains were mixed with these beds at the time when they were deposited, the agent, (probably *heat*) by means of which these beds were solidified and elevated above the surface of the sea, was powerful enough to obliterate all traces of fossil remains. The former of these opinions is much more probable than the latter; for we can hardly conceive any thing short of fusion to be capable of obliterating all remains of shells and bones. But fusion would, at the same time, have obliterated all traces of stratification, which still continues very evident in these rocks. Indeed, the line of demarcation between different beds in these rocks, is often very distinct. This may be seen in the beds of quartz and of limestone which occur in the clay slate mountains of the Grampians.

4. All the formations above the clay slate, contain fossils both of plants and animals, and from the nature of these fossils, they may be divided into several groups.

The first of these begins with the greywacke series, and consists of what are usually called the *transition formations*, the *coal measures*, and the *new red sandstone*; for the fossils in all these great formations approach very nearly to each other. The vegetable fossils are casts of trees, both monocotyledonous and dicotyledonous, equisetaceæ, filices, &c. not one of which is identical with those at present vegetating upon the earth. From the great size which these fossil plants attained, compared with the analogous species at present growing in the torrid zone, it has been concluded, that when these formations were deposited, the temperature was much milder than at present, higher indeed than that of the torrid zone at present. But nothing can be more hazardous than to draw such conclusions from premises so obviously defective. These plants, for any thing that we know to the contrary, though analogous to plants at present vegetating in the torrid zone, may have been adapted for a colder climate; just as the mammoth, as was evident from the immense quantity of hair with which the carcase found in Siberia was clothed, was intended by nature to live in the cold climate of the north of Europe, and Asia and America.

The animal fossils consist of remains of *fish*, hardly any of which have been determined, and certainly not agreeing with any species of fish at present known to exist. Zoophyta, radiaria, annulata, conchifera, mollusca, and crustacea, are the only other classes of animal fossils that have been observed. No remains of birds, amphibia, or quadrupeds, have ever occurred in any of the beds, from the greywacke to the new red sandstone inclusive. The deposition of this long suite of beds must have occupied a very long series of years, and during the whole of it we have no evidence that any land animals existed, since all the fossils hitherto discovered belong to sea animals, and, excepting a few fishes, to sea animals of the lowest class. It is certainly possible that land animals might have existed at the time of the deposition of these beds, though the remains of none of them have been detected; yet as such remains are found in the beds situated above the new red sandstone, though wanting in those below it, the probability lies in the supposition that at the deposition of the whole series of beds, from the greywacke to the new red sandstone inclusive the earth was uninhabited by quadrupeds, amphibia, or birds though it abounded in shell fish, and zoophites and crustaceous animals. Now, these are perhaps the very lowest tribes of animals at present inhabiting the earth. It has been already observed, that not a single species found fossil in these beds agrees with any animal at present inhabiting the sea or fresh water. Hence it is clear, that at the deposition of these beds the inhabitants of the ocean were entirely different from those which it contains at present. To what are we to ascribe this circumstance? Certainly to some alteration either in the temperature or the state of the ocean.

5. The second group of fossiliferous formations consists of the oolite, which in England is composed of so great a number of beds. In them the number of fossils is immense. The vegetable fossils are not so numerous as in the coal measures, but more varied. Besides algæ, equisetaceæ and filices, there are found in the oolite fifteen species of cycadeæ, five species of coniferæ, and one species belonging to the natural order of *lily*.

The zoophites, radiaria, and annulata, are exceedingly numerous, and consist in general of species different from those found in the coal beds, though some are common to both; even many of the genera are different. The shells are very numerous, amounting to about seven hundred and fifty species, the greater number of which differ from those in the coal measures. The ammonites and belemnites are particularly abundant. But the remarkable circumstance is, that amphibious animals first make their appearance in the oolite beds. The crocodile, the megalosaurus, geosaurus, plesiosaurus, ichthyosaurus, pterodactylus, &c., to the number of twenty-nine species, have been found, particularly in the lias and the Stonefield slate. It is unnecessary to observe that all these species are extinct. Finally, a species of didelphis or opossum has been found in the Stonefield slate. Remains of fish and even of insects have been also observed, but scarcely in a state of preservation sufficient to enable anatomists to make out the species.

The deposition of the oolite, then, marks a remarkable era in the history of the earth. When the beds of which it is composed were formed at the bottom of the sea, the earth was inhabited by amphibious animals, some of them of prodigious size, and at least one land quadruped of the opossum tribe existed. The vast size of these animals, similar only to those that exist at present in the torrid zone, would seem to indicate that the climate in England, and those parts of France and Germany where such fossils have been found, was much milder than it is at present.

6. The third group of fossiliferous formations is the chalk. In it the number of fossil plants hitherto observed is but small. The fossil shells are exceedingly numerous, and in general different from those in the oolite beds, and all of them belong

to extinct species. But the great tribe of fossils which distinguish the chalk are the *radiaria*, especially galerites and spatangi. No quadruped fossil has been hitherto met with, but several amphibious animals, particularly the Mososaurus Hoffmanni, a species of crocodile, and some other reptiles, whose genera have not been determined.

Thus the chalk formation was deposited at the bottom of the sea before any evidence can be produced that the earth was inhabited by quadrupeds, with the single exception of the didelphis found in the Stonefield slate. All the fossils found in the chalk, and in the formations below the chalk, belong to species of animals and plants no longer existing. Many of the genera even have perished, and all traces of these ancient inhabitants of the earth, except what are deducible from their fossil remains, are lost.

7. The formations above the chalk exhibit a new era in the history of the earth, as they contain abundance of the fossil remains of land animals, quadrupeds, and even birds. The formations above the chalk, usually called *tertiary*, have been divided, it will be recollected, into three groups; namely, the *eocene*, the *miocene*, and the *pliocene*.

In the eocene formations, which have been examined with so much care in the neighbourhood of Paris and of London, the number of fossil shells which occur is prodigious. Almost the whole of them belong to extinct species, though there are a very few which still continue to live in the adjacent seas.

It is in this formation that the fossil remains of two new genera of quadrupeds have been found, namely, the *palæotherium* and *anoplotherium;* the former of which resembles the tapir, and the latter the camel. Ten species of the former genus, and five of the latter, have been discovered by Cuvier in the gypsum beds near Paris. Three carnivorous animals have also been found in the same beds. An account has been already given (p. 85) of the 78 different fossil quadrupeds discovered by Cuvier in these beds. To this account the reader is referred to save repetition. It is almost unnecessary to mention, that not one of these species at present exists. All the fossils belong to extinct species of quadrupeds.

Thus when the eocene beds were deposited at the bottom of the sea, the earth contained quadrupeds as it does at present, and several of these animals were of enormous size. But as all the species at that time existing, and even some of the genera, were different from those at present inhabiting the earth, and as almost all the inhabitants of the sea have changed since that period, it is obvious that it must be exceedingly remote; though we have no data to enable us to form even a conjecture respecting the length of time which has elapsed since the deposition of these beds. Their elevation, though long preceding the commencement of history, must of necessity have taken place at a later period.

8. The miocene beds lie over the eocene when both occur together, and therefore are newer. Like the eocene beds they abound in fossil shells, about one-sixth of which still exist in the neighbouring seas. They contain also abundance of fossil bones of quadrupeds, some of which are the same as those that occur in the eocene beds, but by far the greater portion are different. They all belong to extinct species. Thus after the deposition of the eocene beds, a prodigious interval must have taken place before the deposition of the miocene, since almost the whole inhabitants of the earth had during it changed their type.

9. The pliocene beds lie over the miocene when both occur together. They also contain a vast number of fossil shells, about one half of which belong to extinct species, and one half to species still living in the neighbouring seas. Mr. Lyell is of opinion that many of the extinct volcanoes may be referred to the pliocene period. It is therefore referrible to a time much posterior to the miocene, though we have no data to conjecture about dates. Fossil quadrupeds have not yet been much met with in these beds. Doubtless they will in general belong to extinct genera. But the investigation of the pliocene beds is still very imperfect, except as far as relates to the shells which they contain.

10. Above the pliocene beds, or at least in caverns filled with mud and stalagmite, occur fossil bones of animals, the species of which is now extinct, though all referrible to existing genera. The deposition of these bones is, therefore, referrible to a period of very ancient date, though probably posterior to the deposition of the pliocene beds. These depositions, to which the term *diluvial* has been applied, constitute a tenth era in the history of the earth. The deposition of the alluvial beds, which is still going on, and in which are found the remains of the vegetables and animals at present inhabiting the earth, constitutes an eleventh era, to which the name of *modern* may be applied.

We may now sum up the facts which seem to have been ascertained respecting the history of the earth in a few sentences.

When it came originally out of the hands of the Creator it was in a liquid state, and it assumed its present shape before it became solid. Hence the axis can have undergone no change since the original solidification, and the old notion entertained by Halley and others about the interior of the globe being hollow, cannot be correct. The mean specific gravity of the earth is even incompatible with the idea that any great portion of the interior is filled with water.

What was the original structure of the earth after its solidification we have no means of knowing, because all the rocks which at present constitute its crust have been evidently formed at the bottom of the sea by the destruction of former rocks, or have been forced up from below in a state of fusion.

Ten different eras may be distinguished during the formation and deposition of the beds constituting the crust of the earth at the bottom of the sea, during each of which the nature of the vegetables and animals inhabiting the earth underwent great changes. An immense number of ages must have elapsed during these successive depositions of strata.

These beds, after having been thus deposited at the bottom of the sea, must have been elevated by some mighty agent, and gradually raised to their present height above it. For the phenomena are inconsistent with the notion of any great subsidence of the surface of the sea.

There is one other topic to which it may be proper barely to allude, before bringing this part of the work to a conclusion. It has been affirmed by some that the discoveries made by geologists are inconsistent with the Mosaic account of the creation; and, on this account, attempts have been made by well-meaning, but ill-advised individuals, to prevent the cultivation of geological science. Nothing can be worse judged than such an attempt; it is a kind of acknowledgment that improvement in science is inconsistent with the prosperity of the Christian religion, and that ignorance is the mother of devotion.

These opinions on both sides proceed entirely from mistaken views. It never was the intention of revelation to teach science to mankind. Such a proceeding would have been inconsistent with the obvious intention of the Deity—that scientific investigations should occupy mankind, and that progress in them should be rewarded by a feeling of happiness of no ordinary kind, resulting from their successful pursuit.

The object of revelation was obviously to teach mankind their duties to their God, their neighbour and themselves. Had it displayed more science than existed at the time when it was made, it would not only have defeated the very object in view, but it would have been necessarily unintelligible to those for whom it was intended.

The cosmogony of Moses is nothing more than this: "In the beginning God created the heavens and the earth;" a proposition which no man of science can refuse to admit, and with which all true geological knowledge is perfectly compatible. To attempt to deduce geological theories from the writings of Moses, is to apply these writings to a purpose for which they were never intended, and to which they can never apply.

The following table exhibits a view of the fossil plants hitherto found and classified, arranged according to the formations in which they occur.

I. FOSSIL PLANTS IN TRANSITION FORMATIONS.

1. *Dicotyledones.*

Genus I. Sigillaria tesselata.
    Voltzii.
  II. Stigmaria ficoides.
  III. Asterophyllites pygmæa.

2. *Filices.*

Genus I. Cyclopteris flabellata, Br. lxi. 4, 5, 6.
  II. Sphenopteris dissecta.
  III. Neuropteris Soretii, Br. lxx. 2.
  IV. Pecopteris aspera.

3. *Lycopodiaceæ.*

Genus I. Calamites radiatus, Br. xxvi. 1, 2.
    Voltzii, Br. xxv.

4. *Algæ.*

Genus I. Fucoides antiquus, Br. iv. 1.
    circinatus, Br. iii. 5.
    dentatus, Br. vi. 9 to 12.
    Serra, Br. vi. 7, 8.

II. FOSSIL PLANTS IN COAL.

1. *Dycotyledones.*

Genus I. Sigillaria alveolaris.
appendiculata.
Boblayi.
Brardii.
Candollii.
canaliculata.
Cortei.
cuspidata.
Davreuxii.
Dournaisii.
elegans.
elliptica.
elongata.
hexagona.
Hippocrepis.
Knorrii.
lævigata.
lævis.
mammillaris.
monostachya, L. and H. lxxii.
notata.
oculata, L. and H. lix.
orbicularis.
organum, L. and H. lxx.
pachyderma, L. and H. liv.
peltigera.
punctata.
reniformis, L. and H. lxxi.
Serlii.
subrotunda.
tesselata.
transversalis.
trigona.
II. Favularia tesselata, L. and H. lxxiii. lxxiv. lxxv.
III. Stigmaria ficoides.
fucoides, L. and H. xxxi. to xxxvi.
intermedia.
minima.
reticulata.
rigida.
tuberculosa.

Stigmaria Weltheimiana.
IV. Bothrodendron punctatum, L. and H. lxxx. lxxxi.
V. Pinites Brandlingi, L. and H. i.
Eggensis, L. and H. iii.
medullaris, L. and H. iii.
Withami, L. and H. ii.
VI. Knorria taxina, L. and H. xcv.
sellonii, L. and H. xcvii.
VII. Sphenophyllum dentatum.
dissectum.
emarginatum.
erosum, L. and H. xiii.
quadrifidum.
Schlotheimii.
truncatum.
VIII. Peuce Withami, L. and H. xxiii. xxiv. and xxv.
vii. viii.
IX. Asterophyllites Brardii.
comosa.
delicatula.
diffusa.
equisetiformis, L. and H. cxxiv.
foliosa.
galioides.
grandis, L. and H. xvii.
hippuroides.
longifolia.
rigida.
tenuifolia.
tuberculata, L. and H. xiv.
X. Pinnularia capillacea, L. and H. cxi.
XI. Hippurites gigantea, L. and H. cxiv.
XII. Megaphyton approximatum, L. and H. cxvi.
distans, L. and H. cxvii.
XIII. Halonia tortuosa, L. and H. lxxxv.
gracilis, L. and H. lxxxvi.
XIV. Phyllotheca.
XV. Annularia brevifolia.
fertilis.
floribunda.
longifolia.
minuta.
radiata.
spinulosa.

Genus XVI. Bechera grandis.

2. *Monocotyledones.*

Genus I. Nœggerathia flabellata, L. and H. xxviii. xxix.
foliosa.
II. Flabellaria borassifolia.
III. Cannophyllites Virletii.
IV. Cyperites bicarinata, L. and H. xliii.
V. Poacites æqualis.
striata.
VI. Sternbergia angulosa.
approximata.
distans.

3. *Filices.*

Genus I. Cyclopteris dilatata, L. and H. xci. B.
obliqua, L. and H. xc. Br. lxi.
orbicularis, Br. lxi. 1, 2.
reniformis, Br. lxi. bis. i.
trichomanoides, Br. lxi. bis. iv.
II. Glossopteris angustifolia, Br. lxiii. 1.
Browniana, Br. lxii.
III. Schizopteris adnascens, L. and H. ci.
anomala.
IV. Caulopteris primeva, L. and H. xlii.
V. Sphenopteris acuta, Br. lvii, 6, 7.
adiantoides, L. and H. cxv.
affinis, L. and H. xlv.
alata, Br. xlviii. 4.
artemisiæfolia, Br. lvi. and lvii. 1, 2.
asplenioides, Sternb. xvi.
bifida, L. and H. liii.
Brardii.
caudata, L. and H. xlviii.
conferta, Sternb. vi. 16.
crenata, L. and H. xxxix. c.
crithmifolia, L. and H. xlvi.
delicatula, Br. lviii. 4.
dilatata, L. and H. xlvii.
dissecta, Br. xlix. 2, 3.
distans, Br. liv. 3.
Dubuissonis, Br. liv. 4.
elegans, Br. liii. 1, 2.
fragilis.

Sphenopteris furcata, Br. xlix. 4, 5.
gracilis, Br. liv. 2.
Gravenhorstii, Br. lv. 3.
Hœninghausi, Br. lii.
latifolia, Br. lvii. 1, 2, 3, 4, 5.
linearis, Br. liv. 1.
Loshii.
nervosa, Br. lvi. 2.
obovata, L. and H. cix.
obtusiloba, Br. liii. 2.
rigida, Br. liii. 4.
Schlotheimii, Br. li.
stricta, Br. xlviii. 2.
tenella, Br. xlix. 1.
tenuifolia, Br. xlviii. 1.
trichomanoides, Br. xlviii. 3.
tridactylites, Br. l.
trifoliata, Br. liii. 3.
Virletii, Br. lviii. 1, 2.
multifida, L. and H. cxxiii.

Genus VI. Neuropteris acuminata, L. and H. li. Br. lxiii. 4.
acutifolia, Br. lxiv. 6, 7.
angustifolia, Br. lxiv. 3, 4.
auriculata, Br. lxvi.
Cistii, Br. lxx. 3.
conferta, Sternb. xvii.
cordata, L. and H. xli. Br. lxiv. 5.
crenulata, Br. lxiv. 2.
decurrens, Sternb. xvii.
elongata, Sternb. xvii.
flexuosa, Br. lxv. 2, 3, and lxviii. 2.
gigantea, L. and H. lii. Br. lxix.
Grangeri, Br. lxviii. 1.
heterophylla, Br. lxxi. and lxxii. 2.
Loshii, L. and H. xlix. Br. lxxii. 1, and lxxiii.
macrophylla, Br. lxv. 1.
microphylla, Br. lxxiv. 6.
oblongata.
obovata, Sternb. xvi.
plicata, Sternb. xvi.
rotundifolia, Br. lxx. 1.
Scheuchzeri, Br. lxiii. 5.

Neuropteris Soretii, L. and H. l.
tenuifolia, Br. lxxii. 3.
Villiersii, Br. lxiv. 1.
Genus VII. Pecopteris abbreviata.
adiantoides, L. and H. xxxvii.
affinis, Br. c. 2, 3.
aquilina, Br. xc.
arborescens, Br. cii. and ciii. 1.
arguta, Br. cviii. 3.
aspera.
aspidoides, Br. cxii. 2.
blechnoides.
Brardii.
Bucklandi, Br. xcix. 2.
Candolliana, Br. c. 1.
cistii, Br. ciii.
conchitica.
crenulata, Br. lxxxvii. 1.
cristata.
cyathea, Br. ci. 1, 2, 3, 4.
Davreuxii, Br. lxxxix.
Defrancii, Br. cxi. and cxii. 1.
gigantea.
Grandini, Br. xci. 1—4.
hemitelioides, Br. cviii. 1, 2.
heterophylla, L. and H. xxxviii.
Lepidorachis, Br. ciii. 1, 5.
lonchitis, Br. lxxxiv. 1—7.
longifolia, Br. lxxxiii. 2.
Mantelli, Br. lxxxiii. 3, 4.
marginata.
Miltoni, Br. cxiv.
nervosa, L. and H. xciv., Br. xc
and xcv. 1, 2.
Nestleriana, Br. cxii. iv.
obliqua, Br. cxvi. 1—4.
oreopteridis, Br. civ. 1, 2, and cv.
2, 3.
ovata, Br. cvii. 4.
platyrachis, Br. ciii. 4, 5.
Pluchenetii, Br. cvii. 1, 2, 3.
Polymorpha, Br. cxiii.
pteroides, Br. cv.

Pecopteris repanda, L. and H. lxxxiv.
Sauveurii, Br. xcv. v.
Schlotheimii.
Serlii.
Serra, L. and H. cvii.
sinuata, Br. xciii. 3.
laciniata, L. and H. cxxii.
VIII. Odontopteris Brardii, Br. lxxv. and lxxvi.
crenulata, Br. lxxviii. 1, 2.
minor, Br. lxxvii.
obtusa, L. and H. xl.
Schlotheimii, Br. lxxviii. 5.

4. *Lycopodiaceæ.*

[illegible]us I. Lycopodites affinis.
filiciformis.
Gravenhorstii.
Hœninghausii.
imbricatus.
phlegmarioides.
piniformis.
tenuifolius.
II. Selaginites erectus.
patens.
III. Ulodendron majus, L. and H. v.
minus, L. and H. vi.
IV. Lepidophyllum, 5 species.
V. Lepidodendron acerosum, L. and H. vii.
aculeatum.
Bobleyi.
Bucklandi.
cælatum.
carinatum.
confluens.
cordatum.
crenatum.
distans.
dubium.
elegans, L. and H. cxviii.
emarginatum.
gracile, L. and H. ix.
Harcourtii, L. and H. xcviii.
xcix.

Lepidodendron imbricatum.
insigne.
lanceolatum.
læve.
laricinum.
lineare.
longifolium.
majus.
obovatum.
Ophiurus.
ornatissimum.
ornatum.
pulchellum.
Rhodianum.
rimosum.
rugosum.
selaginoides.
Sternbergii.
taxifolium.
tetragonum.
transversum.
trinerve.
Underwodii.
undulatum.
varians.
venosum.
Volkmannianum.

5. *Equisetaceæ.*

Genus I.* Equisetum dubium, Br. xii. 17, 18.
infundibuliforme, Br. xii. 16.
II. Calamites approximatus, Br. xxiv. xxv. 7, 8.
cannæformis, L. and H. lxxix. Br. xxi.
cistii, Br. xx.
cruciatus, Br. xix.
decoratus, Br. xiv. 1 to 5.
dubius, Br. xviii. 1 to 3.
Mougeotii, Br. xxv. 4, 5.
nodosus, L. and H. xv. xvi. Br. xxiii. 2 to 4.
pachyderma, Br. xxii.
ramosus, Br. xvii. 5, 6.
Steinhaueri, Br. xviii. 4.

Suckowii, Br. xiv. 6, and xv. 1—6, and xvi.
undulatus, Br. xvii. 1—4.

6. *Confervaceæ.*

Genus I. Confervites thoreæformis, Br. ix bis. 3, 4.

7. *Fucaceæ.*

Genus I. Fucoides.
Only the one I found in Ayrshire.

III. PLANTS IN NEW RED SANDSTONE.

1. *Bicotyledones.*

Genus I. *Juglans.
II. Æthophyllum stipulare.
III. Echynostachys oblongus.
IV. Cupressites Ullmanni.
V. Voltzia acutifolia.
brevifolia.
elegans.
heterophylla.
rigida.

2. *Monocotyledones.*

Genus I. Convallarites erecta.
nutans.
II. Paleoxyris regularis.

3. *Filices.*

Genus I. Sphenopteris myriophyllum, Br. lv. 2.
Palmetta, Br. lv. 1.
II. Neuropteris Dufresnoii, Br. lxxiv. 4, 5.
elegans, Br. lxxiv. 1, 2.
Gaillardoti, Br. lxxiv. 3.
Voltzii, Br. lxvii.
III. Pecopteris Sulziana, Br. cv. 4.
IV. Anomopteris Mougeotii, Br. lxxix. lxxx. lxxxi.
V. Filicites scolopendroides.
VI. Calamites arenaceus, Br. xxv. 1 and xxvi, 3, 4, 5.

4. *Fucaceæ.*

Genus I. Fucoides Brardii.

Fucoides digitatus.
frumentarius.
lycopodioides.
pectinatus.

IV. PLANTS IN OOLITE.

1. *Bicotyledones.*

Genus I. Stigmaria. Mammillaria Desnoyersii.
II. Peuce, several species.
III. Taxites podocarpoides.
IV. Thuytes acutifolia.
cupressiformis.
divaricata.
expansa.
V. Zamia acuta.
elegans.
Feneonis.
Goldiæi.
lævis.
longifolia.
Mantelli.
patens.
pectinata.
pennæformis.
Youngii.
VI. Zamites Bechii.
Bucklandii.
hastata.
Lagotis.
VII. Pterophyllum comptum, L. and H. lxiii.
minus, L. and H. lxvii.
Pecten, L. and H. cii.
Williamsonis.
VIII. Nilsonia. Two species in the sandstone of the lias.
IX. Cycadeoides. Two species in the Portland stone.
X. Araucaria peregrina, L. and H. lxxxviii.
XI. Dictyophyllum rugosum, L. and H. civ.

2. *Monocotyledones.*

Genus I. Zosterites. One? species in lias.

II. Bucklandia squamosa.
III. Ctenis foliata.

3. *Filices.*

Genus I. Cyclopteris Beanii, L. and H. xliv.
    digitata, L. and H. lxiv. Br. lxi bis. 2, 3.
II. Glossopteris Nilsoniana, Br. lxiii. 3.
    Phillipsii, L. and H. lxiii.
III. Sphenopteris crenulata, Br. lvi. 3.
    denticulata, Br. lvi. 1.
    hymenophylloides, Br. lvi. 4.
    Williamsonis, Br. xlix. 6, 7, 8.
IV. Pecopteris Beaumontii, Br. cxii. 3.
    denticulata, Br. xcviii. 1, 2.
    Desnoyersii.
    insignis, L. and H. cvi.
    Meriani, Br. xci. 5.
    nebbensis, Br. xcviii. 3.
    polypodioides, L. and H. lx.
    Phillipsii, Br. cix. 1.
    Reglei.
    tenuis, Br. c. 3, 4.
    Whitbiensis, Br. cix. 2, 3, 4.
    Williamsonis, Br. c. 1, 2, L. and H. 126.
    propinqua, L. and H. cxix.
    undans, L. and H. cxx.
V. Pachypteris lanceolata, Br. xlv. 1.
    ovata, Br. xlv. 2.
VI. Tæniopteris latifolia, Br. lxxxii. 6.
    major, L. and H. xcii.
    vittata, L. and H. lxii.
VII. Clathropteris, 1 species.
VIII. Neuropteris arguta, L. and H. cv.
    ingens, L. and H. xci. A.
    ligata, L. and H. lxix.
    recentior, L. and H. lxviii.
    undulata, L. and H. lxxxiii.
IX. Solenites Murrayana, L. and H. cxxi.

4. *Lycopodiaceæ.*

Genus I. Lycopodites foliatus, L. and H. lxi.
    Williamsonis, L. and H. xciii.

Genus II. Equisetum columnare, Br. xiii. 1—6.

5. *Fucaceæ.*

Genus I. Fucoides Brardii, Br. ii. 8—19.
digitatus, Br. ix. 1.
encœlioides, Br. vi. 1, 2.
frumentarius, Schlot. xxviii. 1.
furcatus, Br. v. 1.
Lycopodioides, Br. ix. 3.
orbignianus, Br. ii. 6, 7.
pectinatus, Schlot. xxvii. 2.
Selaginoides, Br. ix. 2.
septentrionalis, Br. ii. 24.
Stockii, Br. vi. 3, 4.

V. PLANTS IN GREEN SAND.

1. *Dicotyledones.*

Genus I. Zamia macrocephala, L. and H. cxxv.

2. *Monocotyledones.*

Genus I. Zosterites, 4 species ?[*]
II. Clathraria Lyellii.

3. *Filices.*

Genus I. Sphenopteris Mantelli.
II. Pecopteris Reichiana.
III. Lonchopteris Mantelli.

4. *Fucoides.*

Genus I. Fucoides æqualis, Br. v. 4.
difformis, Br. v. 5.
intricatus, Br. v. 6, 7, 8.
recurvus, Br. v. 2.
strictus, Br. ii. 1—5.
Targionii, Br. iv. 2—6.
tuberculosus, Br. vii. 5.

VI. PLANTS IN CHALK.

1. *Dicotyledones.*

Genus I. Cycadites Nilsonii.

[*] Do they not rather belong to the chalk ?

2. *Monocotyledones.*

Genus I. Zosterites Bellovisana.
caulinisæfolia.
elongata.
lineata.

3. *Confervæ.*

Genus I. Confervites ægagropiloides.
fasciculata.

4. *Fucoides.*

Genus I. Fucoides Brongniarti.
canaliculatus.
cylindricus, Br. iii. 4.
difformis.
intricatus.
Lyngbianus, Br. ii. 20, 21.
Orbignianus.
strictus.
Targioni.
tuberculosus.

VII. PLANTS IN BEDS ABOVE THE CHALK, PROBABLY MIOCENE.

1. *Musci.*

Genus I. Muscites squamatus, Br. x. 5—7.
Tournalii, Br. x. 1, 2.

2. *Equisetaceæ.*

Genus I. Equisetum brachyodon, Br. xii. 11, 12.
Meriani? Br. xii. 13.

3. *Filices.*

Genus I. Tæniopteris Bertrandi, Br. lxxxii. 5.

4. *Algæ.*

Genus I. Fucoides Agardhianus, Br. vi. 5, 6.
Bertrandi, Br. vii. 1, 2.
discophorus, Br. viii. 6.
flabellaris, Br. viii. 5.
gazolanus, Br. viii. 3.
Lamourouxii, Br. viii. 2.

Fucoides multifidus, Br. v. 9, 10.
Nilsonianus, Br. ii. 22, 23.
obtusus, Br. viii. 4.
spathulatus, Br. vii. 4.
Sternbergii, Br. iii. 1.
turbinatus, Br. viii. 1.

BICOTYLEDONOUS PLANTS FOUND IN THE TERTIARY BEDS.

Genus I. *Ulmus, 1.
II. *Carpinus, 1.
III. *Castanea, 1.
IV. *Betula, 1.
V. *Salix, 1.
VI. *Populus, 2.
VII. *Comptonia, 1.
VIII. *Juglans, 3.
IX. *Acer, 1.
X. *Pinus, 9.
XI. *Abies, 1.
XII. Taxites, 5.
XIII. Juniperites, 3.
XIV. *Thuya, 4.

MONOCOTYLEDONOUS PLANTS IN TERTIARY BEDS.

Genus I. Antholithes, 1.
II. Flabellaria, 1.
III. Palmacites, 1.
IV. Phænicites, 1.
V. *Cocos, 3.
VI. Culmites, 3.
VII. Amomocarpum, 1.
VIII. Pandanacarpum, 1.
IX. *Chara, 5.
Besides many fruits.

VIII. PLANTS IN FRESH WATER FORMATIONS.

Genus I. *Nymphæa, 1.
II. *Cinnamomum, 1.
III. *Comptonia, 1.
IV. *Podocarpus, 1.

Genus V. Smilacites, 1.
VI. Flabellaria, 1.
VII. Zosterites, 2.
VIII. Phyllites, 1.

In the preceding catalogue I have noticed very few of the fossil fruits, because it has been impossible to determine the kind of plants to which they belong. A description, and figures, of a considerable number of these fossil fruits, found in the Isle of Sheppy, by Dr. Parsons, will be found in the *Philosophical Transactions* for 1757, page 396.

DESCRIPTION OF THE GENERA OF FOSSIL PLANTS HITHERTO CLASSIFIED.

1. *Dicotyledonous Plants.*

Genus I.—*Sigillaria.* This generic name has been given to the large stems so frequently found upright in the sandstone in coal districts. Sternberg has applied to them the name *Rhytidolepis*, and *Artis* that of *Euphorbites*. A very remarkable specimen, found immediately above the coal in Killingworth Colliery, is figured and described in the *Transactions of the Natural History Society of Newcastle*, vol. i. page 206, by Mr. Nicholas Wood. From this it has been copied into Lindley and Hutton's *Fossil Flora*, plate 54, vol. i. p. 149. Various opinions have been started respecting the analogy of these stems to existing plants. Mr. Artis thinks that they are related to the Euphorbiaceæ; Schlotheim refers them to Palms; Brongniart at first considered them as completely different from any thing at present known; but now, with Count Sternberg, he places them among the *ferns.*

I think Messrs. Lindley and Hutton have shown clearly that they have no analogy to ferns. As these stems exhibit a true and separable bark, always in the fossil specimens converted into coal, it is evident that they belonged to dicotyledonous plants. But what are the analogous living plants, or whether there be any living plant, to which they bear any analogy, are questions that the present state of our knowledge does not enable us to answer.

When they lie in the direction of the strata these stems are always pressed flat, and are usually distinguished by oval or variously shaped scars disposed in regular rows longitudinally on the stem. It was from this probably that Sternberg distinguished them by the name of Syringodendron.

Genus II.—*Favularia.* This, like the last genus, constitutes casts of stems in the sandstone of the coal formation. It resembles sigillaria, only the rows of scars run longitudinally, or parallel to the axis of the stem, each row being separated by a groove. They are much smaller and more numerous than the scars in sigillaria, though the plants are doubtless analogous.

Genus III.—*Stigmaria.* The fossil plants belonging to this curious genus were first accurately described by Steinhauer. It constitutes the most common of the fossil vegetables in the coal formation. From the round cavities somewhat resembling the pits left by the small-pox, it has been distinguished by Sternberg by the name of *Variolaria.* The most perfect form in which it occurs is that of a cylinder more or less compressed, and generally flatter on one side than the other. Pretty often the flattened side turns in so as to form a groove. Mr. Steinhauer has shown that the pustules on the stem constituted the origin of fibres or branches which radiate in all directions from the stem, and he traced them on the banks of a rivulet between the townships of Pudsey and Tong, issuing in rays in every direction, and extending to a distance of above 20 feet from the central stem. This demonstrates that the plant grew originally in a horizontal direction, and shot out its fibres in every direction through the yielding mud. Messrs. Lindley and Hutton have shown that the stigmaria was a succulent and dicotyledonous plant, and have rendered it probable that what Steinhauer described as fibres or branches were cylindrical leaves, and they consider it as probable that it is intermediate between the Euphorbiaceæ and Cacteæ.

Genus IV.—*Bothrodendron.* Large stems, of which only fragments remain. On the surface of the stem are many minute dots, arranged in quincunces, and something less than half an inch apart. They may be the scars of leaves. At intervals of ten or eleven inches the stem is marked with deep circular concavities, four or five inches across, at the bottom of each of which is a distinct fracture indicating that something has been broken out, while the sides of the cavities have concentric marks, as if from the pressure upon them of rounded scales. From the fragments taken out of these cavities, it is clear that they were the points of attachment of very large cones. Hence there can be no doubt that the plant belonged to the natural order of coniferæ.

Genus V.—*Pinites.* This name has been given to the large stems discovered at Wideopen, near Newcastle-upon-Tyne, and at Craigleith, near Edinburgh. Mr. Witham first proved that they were the stems of dicotyledonous plants, and analogous to pines in their structure. Hence the term *pinites.* Four different species have been described by Lindley and Hutton.

Genus VI.—*Knorria.* This name has been given by Sternberg to certain stems, or fragments of stems, found in the coal formation. Lindley and Hutton have shown that they exactly coincide with the appearance of branches of the Yew. There can be no doubt that they belong to succulent and dicotyledonous plants.

Genus VII.—*Sphenophyllum.* This genus, called *rotularia* by Sternberg, is distinguished by the following characters:—Branches deeply furrowed; leaves verticillate, wedge-shaped, with dichotomous veins. Lindley and Hutton have shown that it approaches nearer to the *coniferæ* than to the filices.

Genus VIII.—*Peuce.* The only known species of this genus was found in sandstone at Ushaw, about four miles north of the city of Durham. Its characters are as follows: Axis composed of pith; wood in concentric circles; bark and medullary rays; but no vessels; walls of the woody fibre marked with oblong deciduous areolæ having a circle in their middle. Mr. Witham has shown that it is the stem of a dicotyledonous plant, and probably a pine. It resembles the Pinites Withami so much that we do not see how they can be distinguished.

Genus IX.—*Asterophyllites.* This genus, the *Bornia* and *Bruckmannia* of Sternberg, is distinguished by the following characters: Stems scarcely tumid at the articulations, branched; leaves verticillate, linear, acute, with a single midrib, quite distinct at their base; fruit a one-seeded? ovate, compressed nucule, bordered by a membranous wing and emarginate at the apex.

Genus X.—*Pinnularia.* This name has been given by Lindley and Hutton to a fossil plant found by Dr. Buckland in the Leebotwood coal pit. It is a branch from which issues at regular distances on opposite sides capillary appendages divided in a pinnated manner. It is obviously the fragme of a dicotyledonous plant.

Genus XI.—*Hippurites.* This name has been given Lindley and Hutton to a fragment of a stem found in Jarr colliery, from its analogy to the genus *hippuris.*

Genus XII.—*Megaphyton.* This name has been given Lindley and Hutton to a fossil plant found in the roof of t high main coal at Jarrow. It is a portion of a dotted st with scars of leaves placed in parallel lines.

Genus XIII.—*Halonia.* This name has been given Lindley and Hutton to those fossil stems which resemble t *lepidodendra* in their rhomboidal scars, but want the dicho mous mode of branching. This brings them nearer to t coniferæ than the lycopodiaceæ to which the lepidodenc have been referred.

Genus XIV.—*Phyllotheca.* The characters of this gen are as follows: Stem simple, straight, articulated, surround at equal distances by sheaths, having long linear leaves, wh have no distinct midrib.

Genus XV.—*Annularia.* This genus, the *Bornia* of Ste berg, is characterized as follows: Stem slender, articulat with opposite branches springing from above the leave leaves verticillate, flat, usually obtuse, with a single midr united at their base, of unequal length.

Genus XVI.—*Bechera.* Only one species of this gen has been met with. It occurs in the coal formation, and characters are as follows:—Stem branched, jointed, tumid the articulations, deeply and widely furrowed. Leaves ve cillate, very narrow, acute, ribless?

Genus XVII.—*Æthophyllum.* Only one species of t genus has been observed; it is situated in the new red sa stone. Its characters are as follows:—stem simple, lea alternate, linear, ribless, not sheathing, having at the base t smaller linear leaflets. Inflorescence spiked; spikes ova Flowers numerous, with a subcylindrical tube or inferior o rium, and a bilabiate? perianthium with subulate segmen Brongniart refers this genus to monocotyledons; but the abo characters belong to no known natural class.

Genus XVIII.—*Echinostachys.* One species only of t genus in the new red sandstone. Inflorescence an oblo spike, beset on all sides with sessile, contiguous, subconic flowers or fruits. Brongniart refers this also to monocotyl dons; but of this there is hitherto no evidence.

Genus XIX.—*Cupressites.* Branches arranged irregularly. Leaves inserted spirally, in six or seven rows, sessile, enlarged at their base. Fruit consists of peltate scales, marked with a conical protuberance in their centre.

Genus XX.—*Voltzia.* A genus of coniferous plants. Branches pinnated. Leaves inserted all round the branches, sessile, slightly decurrent or dilated at the base, and almost conical; often distichous. Fruit forming spikes or loose cones, composed of distant imbricated scales, which are more or less deeply three lobed.

Genus XXI.—*Taxites.* A genus of coniferous plants. Leaves solitary, supported on a short petiole, articulated, and inserted in a single spire, not very dense, distichous.

Genus XXII.—*Thuytes.* A genus of coniferous plants. Branches as in Thuya. Fruit unknown.

Genus XXIII.—**Zamia.* A genus belonging to the natural order of Cycadeæ. Leaves pinnated; leaflets entire, or toothed at their extremity, pointed, sometimes enlarged and auricled, as it were, at their base, attached only by the midrib, which is often thickened; veins fine, equal and parallel, or scarcely diverging.

Genus XXIV.—*Zamites.* Branches and leaves as in Zamia.

Genus XXV.—*Pterophyllum.* A genus belonging to the natural order of Cycadeæ. Leaves pinnated; leaflets almost equally broad each way, inserted by the whole of their base, truncated at the summit; veins fine, equal, simple, but little marked, all parallel.

Genus XXVI.—*Nilsonia.* Belongs to the Cycadeæ. Leaves pinnated; leaflets approximated, oblong, more or less elongated, rounded at the summit, adhering to the rachis by the whole of their base, with parallel veins, some of which are much more strongly marked than others.

Genus XXVII.—*Cycadeoidea.* This name has been given by Buckland, to the genus called *Mantellia*, by Ad. Brongniart. Stem roundish or oblong, covered with densely imbricated scales, which are scarred at their apex.

Genus XXVIII.—**Araucaria.* This name has been given by Lindley and Hutton, to a branch about a foot long, found in the lias of Lyme in Dorsetshire. From the branch proceed four or five laterals, spreading widely from the main stem, and slightly curved. The whole closely covered by thick, ovate, blunt leaves, which seem to have had a very broad edge and a rhomboidal figure, overlapping each other nearly half their length; exactly similar to the *Araucaria excelsa*, a coniferous plant of Norfolk island.

Genus XXIX.—*Dictyophyllum.* This name has been given by Lindley and Hutton to a fossil leaf, first described by Mr. Phillips, from the upper sandstone, shale and coal of the oolitic formation in Yorkshire. It is not unlike the leaf of a sow thistle. Doubtless it belonged to a dicotyledonous plant, though no evidence exists to show its nature. The term *dictyophyllum* is employed to designate all fossil leaves of a common reticulated structure; while the term phyllites is applied to those whose principal veins converge at both the base and apex.

Genus XXX.—*Cycadites.* Leaves pinnated; leaflets linear, entire, adhering by their whole base, having a single thick midrib; no secondary veins.

Genus XXXI.—*Juniperites.* Branches arranged irregularly. Leaves short, obtuse, inserted by a broad base, opposite, decussate, and arranged in four rows.

The remaining genera of dicotyledonous plants being recent, are not described, because the student can easily have recourse to those systems of botany in which descriptions of them occur.

2. *Monocotyledonous Plants.*

Genus I.—*Nœggerathia.* A palm. Leaves petiolated, pinnated; leaflets obovate, nearly cuneiform, applied against the edges of the petiole, toothed towards their apex, with fine diverging veins.

Genus II.—*Flabellaria.* A palm. Leaves petiolated, flabelliform, divided into linear lobes, plaited at their base.

Genus III.—*Cannophyllites.* Leaves simple, entire, traversed by a very strong midrib; veins oblique, simple, parallel, all of equal size.

Genus IV.—*Poacites.* This name has been given to all monocotyledonous leaves, the veins of which are parallel, simple, of equal thickness, and not connected by transverse bars.

Genus V.—*Sternbergia.* Called *Columnaria* by Sternberg. Stem taper, slender, naked, cylindrical, terminating in a cone; marked by transverse furrows, but with no articulations. Slight remains of a fleshy cortical integument.

Genus VI.—*Convallarites.* Leaves verticillate, linear, with parallel, slightly marked veins. Stem straight or curved.

Genus VII.—*Palæoxyris.* Inflorescence a terminal fusiform spike, with appressed, closely imbricated scales; its external portion, where it is not covered by scales, rhomboidal, concave in the middle. The tuft of filaments, noticed by Brongniart, as proceeding from its apex, is at variance with Xyris, to which it would otherwise be referred. Is it a dicotyledonous plant?

Genus VIII.—*Zosterites.* Leaves oblong or linear, marked with a small number of equal veins, which are at a marked distance from each other, and are not connected by transverse veins.

Genus IX.—*Bucklandia.* Stem covered by reticulated fibres, giving rise to imbricated leaves, which are not amplexicaul, and the petioles of which are distinct to their base.

Genus X.—*Ctenis.*

Genus XI.—*Clathraria.* Stem composed of an axis, the surface of which is covered by reticulated fibres, and of a bark formed by the complete union of the bases of petioles, whose insertion is rhomboidal.

Genus XII.—*Antholithes.* The flower only of a species of this genus has been met with in the beds above the chalk.

Genus XIII.—*Palmacites.*

Genus XIV.—*Phœnicites.* A palm. Leaves petiolated, pinnated; leaflets linear, united by pairs at the base; their veins fine and little marked.

Genus XV.—**Cocos.* A palm. The fruit only of this palm has been found fossil. Fruit ovate, slightly three cornered, marked with three orifices near their base.

Genus XVI.—*Culmites.* Stem articulated, with two or more scars at the joints.

Genus XVII.—*Amomocarpum.* Fruit only found: analogous to that of ginger.

Genus XVIII.—*Pandanocarpum.* Fruit only found; analogous to that of *Pandanus*, or *screw pine-tree* of the Isle of France.

Genus XIX.—*Smilacites.* Leaves heart-shaped, or hastate, with a well defined midrib, and two or three secondary ribs on each side, parallel to the edge of the leaf: veins reticulated.

Genus XX.—*Phyllites.* This is the *Potamo-phyllites* of Brongniart. It includes all monocotyledonous leaves, the veins of which are confluent at the base and apex, and connected by transverse bars or secondary veins.

Genus XXI.—**Chara.* Fruit, oval or spheroidal, consisting of five valves twisted spirally; a small opening at each extremity. Stems friable, jointed, composed of straight tubes arranged in a cylinder.

3. *Filices.*

Genus I.—*Cyclopteris.* Leaves simple, entire, somewhat orbicular; veins numerous, radiating from the base, dichotomous, equal; midrib wanting.

Genus II.—*Glossopteris.* Leaves simple, entire, somewhat lanceolate, narrowing gradually to the base, with a thick vanishing midrib; veins oblique, curved, equal, frequently dichotomous, or sometimes anastomosing and reticulated at the base.

Genus III.—*Schizopteris.* Leaves linear, plane, without midrib, finely striated, almost flabelliform, dividing into several lobes, which are linear and dichotomous, or rather irregularly pinnated, and erect; lobes dilated and rounded towards the extremity.

Genus IV.—*Caulopteris.* A tree fern. Stem cylindrical, closely marked by large, oblong, convex, uneven scars, wider than the tortuous depressed spaces that separate them.

Genus V.—*Sphenopteris.* Leaves bi-tripinnatifid; leaflets contracted at the base, not adherent to the rachis, lobed; the lower lobes largest, diverging, somewhat palmate; veins bipinnate, radiating, as it were, from the base.

Genus VI.—*Neuropteris.* Leaves bipinnate, or rarely pinnate; leaflets usually somewhat cordate at the base, neither adhering to each other nor to the rachis, by their whole base, only by the middle portion of it; midrib vanishing at the apex; veins oblique, curved, very fine, dichotomous—*Fructification;* sori lanceolate, even (covered with an indusium), arising from the veins of the apex of the leaflets, and often placed in the bifurcations.

Genus VII.—*Pecopteris.* Leaf once, twice, or thrice pinnate; leaflets adhering by their base to the rachis, or occasionally distinct; midrib running quite through the leaflet; veins almost perpendicular to the midrib, simple, or once or twice dichotomous.

Genus VIII.—*Odontopteris.* Leaves bipinnated; leaflet membranous, very thin, adhering by their base to the rachis, with no, or almost no, midrib; veins equal, simple, or forked, very fine, most of them springing from the rachis.

Genus IX.—*Anomopteris.* Leaves pinnated; leaflets linear, entire, somewhat plaited transversely at the veins, having a midrib; veins simple, perpendicular, curved. *Fructification* arising from the veins, uncertain as to form; perhaps dot-like and inserted in the middle of the veins; or perhaps linear, attached to the whole of a vein, naked (as in Meniscia) or covered by an indusium, opening inwardly.

Genus X.—*Tæniopteris.* Leaves simple, entire, with a stiff, thick midrib; veins perpendicular, simple, or forked at the base. *Fructification* dot-like.

Genus XI.—*Clathropteris.* Leaf deeply pinnatifid; leaflets having a very strong complete midrib; veins numerous and simple, parallel, almost perpendicular to the midrib, united by transverse veins, which form a network of square meshes upon the leaf.

Genus XII.—*Lonchopteris.* Leaf many times pinnatifid; leaflets more or less connate at the base, having a midrib; veins reticulated.

Genus XIII.—*Pachypteris.* Leaves pinnated or bipinnated; leaflets entire, coriaceous, ribless, or one-ribbed, contracted at the base, but not adherent to the midrib.

Genus XIV.—*Filicites.* To this are referred all the fossil ferns which do not belong to any of the preceding genera.

4. *Equisetaceæ.*

Genus I.—*Calamites.* Stem jointed, regularly and closely furrowed, hollow, divided internally at the articulations by a transverse diaphragm, covered with a thick cortical integument. Leaves? verticillate, very narrow, numerous, simple.

Genus II.—**Equisetum.* Stems articulated, surrounded by cylindrical sheaths, which are regularly tooth-letted and pressed close to the stem.

5. *Lycopodiaceæ.*

Genus I.—*Lycopodites.* Branches pinnated; leaves inserted all round the stem in two opposite rows, not leaving clean and well defined scars.

Genus II.—*Selaginites.* Stems dichotomous, not presenting regular elevations at the base of the leaves, even near the lower end of the stems. Leaves often persistent, enlarged at their base.

Genus III.—*Ulodendron.* Stem covered with rhomboidal areolæ, which are broader than long; scars large, few, placed one above another, circular, composed of broad cuneate scales, radiating from a common centre, and indicating the former presence of organs analogous to the cones of coniferæ.

Genus IV.—*Lepidodendron.* Stems dichotomous, covered near their extremities by simple, linear, or lanceolate leaves, inserted upon rhomboidal areolæ; lower part of the stems leafless; areolæ (longer than broad) marked near their upper part by a minute scar, which is broader than long, and has three angles, of which the two lateral are acute, the lower obtuse; the latter sometimes wanting.

Genus V.—*Lepidophyllum.* Stem unknown; leaves sessile, simple, entire, lanceolate, or linear, traversed by a single midrib, or by three parallel ribs; no veins.

6. *Musci.*

Genus I.—*Muscites.* Stem simple, or branched, filiform, with membranous leaves, having scarcely any midrib, and being sessile or amplexicaul, imbricated, or somewhat spreading.

7. *Algæ.*

Genus I.—*Confervites.* Filaments simple or branched, divided by internal partitions.

Genus II.—*Fucoides.* Frond continuous, never articulated, usually not symmetrical or subcylindrical, simple, or oftener branched, naked, or more commonly leafy; or membranous, entire, or more or less lobed, with no ribs, or imperfectly marked ones, which branch in an irregular manner, and never anastomose.

These descriptions of the fossil genera of plants are chiefl translated from the definitions of M. Adolphe Brongniart. A few of them are from the *Fossil Genera of Plants*, drawn u by Messrs. Lindley and Hutton, at the end of the preface t the first volume of their *Fossil Flora*, an exceedingly interes ing and valuable work still going on. It is to be feared th M. Brongniart has not met with that encouragement whic his *Histoire des Végétaux Fossiles* so eminently deserves. long interval has elapsed since the publication of the 9 livraison of that work, which is the last number that we ha seen.

Abbreviations employed in the following Table.

Al. Br.	Alex. Brongniart.	Lin.	Linnæus.
Blain.	Blainville.	List.	Lister.
Broc.	Brocchi.	Mant.	Mantell.
Brug.	Bruguière.	Mill.	Miller.
Cuv.	Cuvier.	Mont.	Montfort.
Dalm.	Dalman.	Munst.	Munster.
Defr.	Defrance.	Nils.	Nilson.
De H.	De Haan.	Park.	Parkinson.
De la B.	De la Beche.	Phil.	Phillips.
Desh.	Deshayes.	Raf.	Rafinesque.
Desm.	Desmarest.	Rein.	Reinecke.
Des M.	Des Moulins.	Schlot.	Schlotheim.
D'Orb.	D'Orbigny.	Schröt.	Schröter.
Flem.	Fleming.	Sm.	Smith.
Goldf.	Goldfuss.	Sow.	Sowerby.
Hoen.	Hoeninghaus.	St. F.	Faujas de St. Fond.
His.	Hisinger.	V. Buch.	Von Buch.
Kön.	König.	Wahl.	Wahlenberg.
Lam.	Lamarck.	Y. & B.	Young and Bird.
Lamx.	Lamouroux.	Ziet.	Zieten.

Table of the Zoophites, Radiata, Crustace

Greywacke.	Coal Formation.	New Red San
	1.	1.
Manon cribrosum, *Goldf.* favosum, *Goldf.*	2.	2.
Scyphia conoidea, *Goldf.* costata, *Goldf.* turbinata, *Goldf.* clathrata, *Goldf.*	3.	3.

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* No attempt has been made to give an enumeration of the shells, &c., in the tertiary
nt engaged in a work on fossil conchology, which will, doubtless, be very complete when it

*lusca, found fossil in the mineral kingdom.**

	Greensand.	Chalk.
oldf. um, Goldf. a, Goldf. , Munst. m, Munst. Munst.	1.	1. Achilleum glomeratum, *Goldf.* fungiforme, *Goldf.* Morchella, *Goldf.*
f.* Munst. unst.	2.	2. Manon Peziza, *Goldf.** tubuliferum, *Goldf.* pulvinarium, *Goldf.* capitatum, *Goldf.* stellatum, *Goldf.*
oldf. df. ldf. df. oldf. f. , Goldf. oldf. Goldf. oldf. oldf. df. lf. oldf. Goldf. Goldf. oldf. oldf. ldf. , Goldf. unst. unst. st. st. oldf. unst. unst. unst. Munst. Munst. i, Munst. , Goldf. nst. oldf. nst. , Munst. Munst. lf.	3.	3. Scyphia mammillaris, *Goldf.* furcata, *Goldf.* infundibuliformis, *Goldf.* foraminosa, *Goldf.* Sackii, *Goldf.* tetragona, *Goldf.*

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pious catalogue to the third volume of Lyell's Geology. M. Deshayes is at pre-

Greywacke.	Coal Formation.	New Red Sandstone
4.	4.	4.
5.	5.	5.
6. Tragos acetabulum, *Goldf.* capitatum, *Goldf.*	6.	6.
7.	7.	7.
8.	8.	8.
9.	9.	9.
10.	10.	10.
11.	11.	11.
12.	12.	12.
13.	13.	13.
14.	14.	14.
15. Gorgonia antiqua, *Goldf.*	15.	15.
16. Stromatopora concentrica, *Goldf.* polymorpha, *Goldf.*	16.	16.
17.	17.	17.
18.	18. Millepora madreporiformis, *Wahl.* cervicornis, *Linn.* repens, *Wahl.* ? foliacea, *Wahl.* ? Retepora, *Wahl.*	18.
19.	19.	19.

ued.

Oolite.	Greensand.	Chalk.
ıgia floriceps, *Phil.*	4.	4. Spongia ramosa, *Mant.*
clavaroides, *Lam.*		lobata, *Hoen.*
		plana, *Phil.*
		capitata, *Phil.*
		osculifera, *Phil.*
		convoluta, *Phil.*
		marginata, *Phil.*
		radiciformis, *Phil.*
		terebrata, *Phil.*
		lævis, *Phil.*
		porosa, *Phil.*
		cribrosa, *Phil.*
	5.	5. Spongus Townsendi, *Mant.*
		labyrinthicus, *Mant.*
gos acetabulum, *Goldf.**	6.	6. Tragos Hippocastanum, *Goldf.*
Patella, *Goldf.*		deforme, *Goldf.*
sphærioides, *Goldf.*		rugosum, *Goldf.*
tuberosum, *Goldf.*		pisiforme, *Goldf.*
pezizoides, *Goldf.*		stellatum, *Goldf.*
radiatum, *Munst.*		
rugosum, *Munst.*		
reticulatum, *Munst.*		
verrucosum, *Munst.*	7.	7. Alcyonium globulosum, *Defr.*
		? pyriformis, *Mant.*
	8.	8. Choanites subrotundus, *Mant.*
		Königi, *Mant.*
		flexuosus, *Mant.*
ıorea mammillaris, *Lamx.*	9.	9.
	10.	10. Ventriculites radiatus, *Mant.*
		alcyonoides, *Mant.*
		Benettiæ, *Mant.*
onia pyriformis, *Goldf.*	11.	11. Siphonia Websteri, *Mant.*
		cervicornis, *Goldf.*
	12. Hallirhoa costata, *Lamx.*	12.
	13. Serea pyriformis, *Lam.*	13.
mecium hemisphæricum, *Goldf.*	14.	14.
gonia dubia, *Goldf.*	15.	15. Gorgonia bacillaris, *Goldf.*
	16.	16.
	17.	17. Nullipora racemosa, *Goldf.*
epora dumetosa, *Lamx.*	18.	18. Millepora Fittoni, *Mant.*
corymbosa, *Lamx.*		Gilberti, *Mant.*
conifera, *Lamx.*		madreporacea, *Goldf.*
pyriformis, *Lamx.*		compressa, *Goldf.*
macrocaulis, *Lamx.*		
straminea, *Phil.*	19.	19. Eschara cyclostoma, *Goldf.*
		pyriformis, *Goldf.*
		stigmatophora, *Goldf.*
		sexangularis, *Goldf.*
		cancellata, *Goldf.*
		arachnoidea, *Goldf.*
		dichotoma, *Goldf.*
		striata, *Goldf.*

Greywacke.	Coal Formation.	New Red Sandstone.
20. Cellepora antiqua, *Goldf.* favosa, *Goldf.*	20. Cellepora Urii, *Flem.*	20.
21. Retepora antiqua, *Goldf.* prisca, *Goldf.*	21. Retepora elongata, *Flem.*	21. Retepora flustracea, virgulacea,
22.	22.	22.
23. Ceriopora verrucosa, *Goldf.* affinis, *Goldf.* punctata, *Goldf.* granulosa, *Goldf.* oculata, *Goldf.*	23.	23.
24.	24.	24.
25.	25.	25.
26. Agaricia lobata, *Goldf.*	26.	26.
27. Lithodendron cæspitosum, *Goldf.*	27.	27.
28.	28. Caryophyllia stellaris, *Linn.* articulata, *Wahl.* truncata, *Linn.* duplicata. affinis. juncea, *Flem.*	28.
29. Anthophyllum bicostatum, *Goldf.*	29.	29.
30.	30.	30.
31.	31. Turbinolia turbinata, *Linn.* echinata, *His.*	31.

ued.

Oolite.	Greensand.	Chalk.
		Eschara filograna, *Goldf.*
		disticha, *Goldf.*
pora orbiculata, *Goldf.*	20.	20. Cellepora ornata, *Goldf.*
echinata, *Goldf.*		Hippocrepis, *Goldf.*
		Velamen, *Goldf.*
		dentata, *Goldf.*
		crustulenta, *Goldf.*
		bipunctata, *Goldf.*
		escharoides, *Goldf.*
	21.	21. Retepora clathrata, *Goldf.*
		lichenoides, *Goldf.*
		truncata, *Goldf.*
		disticha, *Goldf.*
		cancellata, *Goldf.*
	22.	22. Flustra utricularis, *Lam.*
		? reticulata, *Desm.*
		flabelliformis, *Lam.*
pora radiciformis, *Goldf.*	23.	23. Ceriopora micropora, *Goldf.*
striata, *Goldf.*		cryptopora, *Goldf.*
angulosa, *Goldf.*		anomalopora, *Goldf.*
alata, *Goldf.*		dichotoma, *Goldf.*
crispa, *Goldf.*		milleporacea, *Goldf.*
favosa, *Goldf.*		madreporacea, *Goldf.*
radiata, *Goldf.*		tubiporacea, *Goldf.*
compressa, *Munst.*		verticillata, *Goldf.*
orbiculata.		spiralis, *Goldf.*
		pustulosa, *Goldf.*
		compressa, *Goldf.*
		stellata, *Goldf.*
		Diadema, *Goldf.*
		polymorpha, *Goldf.*
		gracilis, *Goldf.*
		spongites, *Goldf.*
		clavata, *Goldf.*
		trigona, *Goldf.*
		Mitra, *Goldf.*
		venosa, *Goldf.*
		cribrosa, *Goldf.*
	24.	24. Lunulites cretacea, *Defr.*
	25. Orbitolites lenticulata, *Lamx.*	25. Orbitolites lenticulata, *Lamx.*
icia rotata, *Goldf.*	26.	26.
crassa, *Goldf.*		
granulata, *Munst.*		
dendron elegans, *Munst.*	27. Lithodendron gibbosum, *Munst*	27.
compressum, *Munst.*	gracile, *Munst.*	
ophyllia cylindrica, *Phil.*	28. Caryophyllia Conulus, *Phil.*	28. Caryophyllia centralis, *Mant.*
truncata, *Lamx.*		
Brebissonii, *Lamx.*		
convexa, *Phil.*		
ophyllum turbinatum, *Munst.*	29.	29.
obconicum, *Munst.*		
decipiens, *Goldf.*		
nolopsis ochracea, *Lamx.*	30.	30.
inolia dispar, *Phil.*	31.	31. Turbinolia mitrata, *Goldf.*
		Königi, *Mant.*

ZOOP

Greywacke.	Coal Formation.	New Red Sandstone.
	Turbinolia pyramidalis, *His.* mitrata, *Schlot.* furcata, *His.*	
32.	32.	32.
33.	33. Fungites patellaris, *Lam.* deformis, *Schlot.*	33.
34.	34.	34.
35. Cyathophyllum Dianthus, *Goldf.* radicans, *Goldf.* marginatum, *Goldf.* explanatum, *Goldf.* turbinatum, *Goldf.* hypocrateriforme, *Goldf.* Ceratites, *Goldf.* flexuosum, *Goldf.* vermiculare, *Goldf.* vesiculosum, *Goldf.* secundum, *Goldf.* lamellosum, *Goldf.* placentiforme, *Goldf.* quadrigeminum, *Goldf.* cæspitosum, *Goldf.* hexagonum, *Goldf.* helianthoides, *Goldf.*	35. Cyathophyllum excentricum, *Goldf.*	35.
36.	36.	36.
37.	37.	37.
38.	38.	38.
39. Strombodes pentagonus, *Goldf.*	39.	39.
40. Astrea porosa, *Goldf.*	40. Astrea interstincta, *Wahl.* undulata.	40. Astrea pediculata,
41.	41.	41.
42. Calamopora alveolaris, *Goldf.* favosa, *Goldf.* Gothlandica, *Goldf.*	42.	42.

nued.

Oolite.	Greensand.	Chalk.
dolites elliptica, *Lam.*	32.	32.
gia orbiculites, *Lamx.*	33.	33. Fungia radiata, *Goldf.* cancellata, *Goldf.* coronula, *Goldf.*
	34. Chenendopora fungiformis, *Lam.*	34.
athophyllum Tintinnabulum, *Goldf.* Mactra, *Goldf.*	35.	35.
	36. Hippalimus fungoides, *Lam.*	36.
	37.	37. Diploctenium cordatum, *Goldf.* Pluma, *Goldf.*
andrina Soemmeringii, *Munst.* astroides, *Goldf.* tenella, *Goldf.*	38.	38. Meandrina reticulata, *Goldf.*
	39.	39.
trea Microconos, *Goldf.* limbata, *Goldf.* concinna, *Goldf.* pentagonalis, *Munst.* gracilis, *Munst.* explanata, *Munst.* tubulosa, *Goldf.* oculata, *Goldf.* alveolata, *Goldf.* helianthoides, *Goldf.* confluens, *Goldf.* caryophylloides, *Goldf.* cristata, *Goldf.* sexradiata, *Goldf.* favosioides, *Sm.* inæqualis, *Phil.* micastron, *Phil.* arachnoides, *Flem.* tubulifera, *Phil.*	40.	40. Astrea flexuosa, *Goldf.* geometrica, *Goldf.* clathrata, *Goldf.* escharoides, *Goldf.* textilis, *Goldf.* velamentosa, *Goldf.* gyrosa, *Goldf.* elegans, *Goldf.* angulosa, *Goldf.* geminata, *Goldf.* arachnoides, *Schröt.* Rotula, *Goldf.* macrophthalma, *Goldf.* muricata, *Goldf.* stylophora, *Goldf.*
	41.	41. Pagrus Proteus, *Defr.*
	42.	42.

Greywacke.	Coal Formation.	New Red Sandstone
Calamopora basaltica, *Goldf.*		
infundibulifera, *Goldf.*		
polymorpha, *Goldf.*		
spongites, *Goldf.*		
fibrosa, *Goldf.*		
43. Aulopora serpens, *Goldf.*	43.	43.
tubiformis, *Goldf.*		
spicata, *Goldf.*		
conglomerata, *Goldf.*		
44.	44.	44.
45. Columnaria alveolata, *Goldf.*	45.	45.
46. Coscinopora Placenta, *Goldf.*	46.	46.
47. Catenipora escharoides, *Lam.*	47. Catenipora fascicularis, *Wahl.*	47.
labyrinthica, *Goldf.*		
tubulosa, *Lam.*		
48.	48. Tubipora tubularia, *Lam.*	48.
49. Syringopora verticillata, *Goldf.*	49. Syringopora cæspitosa, *Goldf.*	49.
50. Favosites Gothlandica, *Lam.**	50. Favosites Gothlandica, *Lam.**	50.
Bromelli, *Ménard.*	Alcyonium, *Defr.*	
truncata, *Raf.*	septosus, *Flem.*	
Kentuckensis, *Raf.*	depressus, *Flem.*	
Boletus, *Ménard.*		
51.	51. Lithostrotion striatum.	51.
	floriforme.	
	marginatum, *Flem.*	
52. Amplexus coralloides, *Sow.**	52. Amplexus coralloides, *Sow.**	52.
53. Mastrema pentagona, *Raf.*	53.	53.
54.	54.	54.
55.	55.	55.
56.	56.	56.
57.	57.	57.
58.	58.	58.
59.	59.	59.
60.	60.	60.
61.	61.	61.
62.	62.	62.
63.	63.	63.

d.

Oolite.	Greensand.	Chalk.
ora compressa, *Goldf.*	43.	43.
dichotoma, *Goldf.*		
ophora cellarioides, *Lamx.*	44.	44.
	45.	45.
	46.	46.
	47.	47.
	48.	48.
	49.	49.
	50.	50.
	51.	51.
	52.	52.
	53.	53.
ora tetragona, *Lamx.*	54.	54.
cæspitosa, *Lamx.*		
elegans, *Lamx.*		
intricata, *Lamx.*		
mia radiata, *Lamx.*	55.	55.
aora damæcornis, *Lamx.*	56.	56.
spinosa, *Lamx.*		
noa clathrata, *Lamx.*	57.	57.
aea triquetra, *Lamx.*	58.	58.
o dichotoma, *Lamx.*	59.	59.
icea diluviana, *Lamx.*	60.	60.
ellaria ramosissima, *Lamx.*	61.	61.
Antilope, *Lamx.*		
ria Smithii, *Phil.*	62.	62.
anasteria Lamourouxii, *Sauv.*	63.	63.

CL

Greywacke.	Coal Formation.	New Red Sandsto
1. Cupressocrinites crassus, *Goldf.* gracilis, *Goldf.*	1.	1.
2. Eugeniacrinites mespiliformis, *Goldf.*	2.	2.
3. Eucalyptocrinites rosaceus, *Goldf.*	3.	3.
4. Sphæronites Pomum, *Wahl.* Aurantium, *Wahl.* granatum, *Wahl.* Wahlenbergii, *Esmark.*	4.	4.
5.	5. Pentremites Derbiensis, *Sow.* ellipticus, *Sow.* ovalis, *Goldf.*	5.
6.	6. Poteriocrinites crassus, *Mill.* tenuis, *Mill.*	6.
7. Platycrinites lævis, *Mill.** rugosus, *Mill.** pentangularis, *Mill.** ventricosus, *Goldf.*	7. Platycrinites lævis, *Mill.** rugosus, *Mill.** pentangularis, *Mill.** granulatus, *Mill.* striatus, *Mill.* tuberculatus, *Mill.* depressus, *Goldf.*	7.
8. Actinocrinites triacontadactylus, *Mill.** lævis, *Mill.** tesseratus, *Goldf.* moniliformis, *Mill.* cingulatus, *Goldf.* muricatus, *Goldf.* nodulosus, *Goldf.* monilifer, *Goldf.*	8. Actinocrinites triacontadactylus, *Mill.** lævis, *Mill.** tesseratus, *Goldf.* polydactylus, *Mill.*	8.
9. Melocrinites lævis, *Goldf.* gibbosus, *Goldf.*	9. Melocrinites hieroglyphicus, *Goldf.*	9.
10. Rhodocrinites verus, *Mill.** gyratus, *Goldf.* quinquepartitus, *Goldf.* canaliculatus, *Goldf.* crenatus, *Goldf.*	10. Rhodocrinites verus, *Mill.**	10.
11. Cyathocrinites tuberculatus, *Mill.* rugosus, *Mill.* geometricus, *Goldf.* pinnatus, *Goldf.*	11. Cyathocrinites planus, *Mill.** quinquangularis, *Mill.*	11. Cyathocrinites plan
12.	12.	12. Encrinites monilifor epithoni ramosus,
13.	13.	13.
14. Pentacrinites priscus, *Goldf.*	14.	14.

IATA.

Oolite.	Greensand.	Chalk.
	1.	1.
	2.	2.
	3.	3.
	4.	4.
	5.	5.
	6.	6.
	7.	7.
	8.	8.
	9.	9.
	10.	10.
	11.	11.
inites echinatus, *Schlot.* mespiliformis, *Schlot.*	12.	12.
crinites rotundus, *Mill.* Prattii, *Gray.* elongatus, *Mill.* rosaceus, *Schlot.* mespiliformis, *Schlot.* Milleri, *Schlot.* flexuosus, *Goldf.* subconicus, *Goldf.*	13.	13. Apiocrinites ellipticus, *Mill.*
acrinites vulgaris, *Schlot.*	14.	14.

R.

Greywacke.	Coal Formation.	New Red Sandston
15.	15.	15.
16.	16.	16.
17.	17.	17. Ophiura prisca, *M* loricata,
18.	18.	18. Asterias obtusa, *G*
19.	19.	19.
20.	20.	20.
21.	21.	21.
22.	22.	22.
23.	23.	23.

d.

Oolite.	Greensand.	Chalk.
nites subangularis, *Mill.*		
Briareus, *Mill.*		
basaltiformis, *Mill.*		
tuberculatus, *Mill.*		
subteres, *Goldf.*		
Jurensis, *Munst.*		
scalaris, *Goldf.*		
cingulatus, *Munst.*		
pentagonalis, *Goldf.*		
monilifer, *Munst.*		
subsulcatus, *Munst.*		
subteres, *Munst.*		
? paradoxus, *Goldf.*		
	15.	15. Marsupites ornatus, *Mill.*
	16.	16. Glenotremites paradoxus, *Goldf.*
	17.	17.
	18.	18.
florigemma, *Phil.*	19. Cidaris variolaris, *Al. Br.**	19. Cidaris variolaris, *Al. Br.**
intermedia, *Park.*		cretosa, *Mant.*
monilipora, *Y. & B.*		claviger, *Kön.*
vagans, *Phil.*		vulgaris, *Lam.*
crenularis, *Lam.*		regalis, *Goldf.*
ornata.		vesiculosa, *Goldf.*
globata, *Schlot.*		scutiger, *Munst.*
maxima, *Munst.*		crenularis, *Lam.*
Blumenbachii, *Munst.*		granulosa, *Goldf.*
nobilis, *Munst.*		saxatilis, *Park.*
elegans, *Munst.*		
marginata, *Goldf.*		
coronata, *Goldf.*		
propinqua, *Munst.*		
glandifera, *Goldf.*		
Schmidelii, *Munst.*		
subangularis, *Goldf.*		
variolaris, *Al. Br.*		
s germinans, *Phil.*	20. Echinus areolatus, *Wahl.*	20. Echinus regalis, *Hoen.*
lineatus, *Goldf.*	Benettiæ, *Kön.*	alutaceus, *Goldf.*
excavatus, *Leske.*		granulosus, *Munst.*
nodulosus, *Munst.*		
hieroglyphicus, *Goldf.*		
sulcatus, *Goldf.*		
es depressus, *Lam.*	21. Galerites ? depressus, *Lam.*	21. Galerites albo-galerus, *Lam.*
speciosus, *Munst.*		vulgaris, *Lam.*
Patella.		subrotundus, *Mant.*
		Hawkinsii, *Mant.*
		abbreviatus, *Lam.*
		canaliculatus, *Goldf.*
		Subuculus, *Linn.*
		sulcato-radiatus, *Goldf.*
s sinuatus, *Park.*	22.	22.
emarginatus, *Phil.*		
cluncicularis, *Sm.*		
dimidiatus, *Phil.*		
semisulcatus, *Phil.*		
orbicularis, *Phil.*		
ster pentagonalis, *Phil.*	23. Clypeaster oviformis, *Lam.*	23. Clypeaster Leskii, *Goldf.*

R

Greywacke.	Coal Formation.	New Red Sandsto
24.	24.	24.
25	25.	25.
26.	26.	26.
27.	27.	27.

CLA

Greywacke.	Coal Formation.	New Red Sandst
1.	1. Cypris Scoto-Bordigalensis, *Hibb.*	1.
2.	2. Daphnoidea, *Hibb.*	2.
3.	3.	3.
4.	4.	4.
5.	5.	5.
6.	6.	6.

Oolite.	Greensand.	Chalk.
		Clypeaster fornicatus, *Goldf.*
	24. Echinoneus Lampas, *De la B.* peltiformis, *Wahl.*	24. Echinoneus subglobosus, *Goldf.* Placenta, *Goldf.*
olites scutatus. columbarius. granulosus, *Munst.* semiglobus, *Munst.* excentricus, *Munst.* canaliculatus, *Munst.*	25. Nucleolites Rotula, *Al. Br.** Lapis Cancri, *Goldf.** castanea, *Al. Br.*	25. Nucleolites Rotula, *Al. Br.** Lapis Cancri, *Goldf.** Ovulum, *Lam.* scrobicularis, *Goldf.* patellaris, *Goldf.* pyriformis, *Goldf.* lacunosus, *Goldf.* cordatus, *Goldf.* carinatus, *Goldf.*
hytes bicordata.	26.	26. Ananchytes ovata, *Lam.* hemisphærica, *Al. Br.* intumescens. pustulosa, *Lam.* conoidea, *Goldf.* striata, *Lam.* sulcata, *Goldf.* Corculum, *Goldf.*
gus ovalis, *Park.* intermedius, *Munst.* carinatus, *Goldf.* capistratus, *Goldf.*	27. Spatangus Cor-anguinum, *Lam.** suborbicularis, *Defr.** retusus, *Park.* Murchisonianus, *Kön.* argillaceus, *Phil.* lævis, *Defr.* Ambulacrum, *Desh.*	27. Spatangus Cor-anguinum, *Lam.** suborbicularis, *Defr.** cordiformis, *Mant.* punctatus, *Lam.* granulosus, *Goldf.* subglobósus, *Leske.* nodulosus, *Goldf.* radiatus, *Lam.* truncatus, *Goldf.* ornatus, *Cuv.* Bucklandii, *Goldf.* Bufo, *Al. Br.* arcuarius, *Lam.* Prunella, *Lam.* Amygdala, *Goldf.* gibbus, *Lam.* Cor-testudinarium, *Goldf.* Bucardium, *Goldf.* lacunosus, *Linn.* hemisphæricus, *Phil.*

USTACEA.

Oolite.	Greensand.	Chalk.
	1. Cypris Faba, *Desm.*	1.
	2.	2.
us modestiformis, *Holl.* minutus, *Holl.* rostratus, *Phil.*	3. Astacus ornatus, *Phil.* longimanus, *Sow.*	3. Astacus Leachii, *Mant.* Sussexiensis, *Mant.*
rus mysticus, *Holl.*	4.	4. Pagurus Faujasii, *Desm.*
arus dubius, *Holl.*	5.	5. Scyllarus Mantelli, *Desm.*
a Cuvieri, *Desm.* Schlotheimii, *Holl.*	6.	6.

CRU

Greywacke.	Coal Formation.	New Red Sandsto
7.	7.	7.
8.	8.	8. Palinurus Sueurii,
9. Calymene Blumenbachii, *Al. Br.*	9. Calymene Blumenbachii, *Al. Br.**	9.
variolaris, *Al. Br.**	variolaris, *Al. Br.**	
macrophthalma, *Al. Br.*	punctata, *Wahl.*	
Tristani, *Al. Br.*	concinna, *Dalm.*	
bellatula, *Dalm.*		
ornata, *Dalm.*		
verrucosa, *Dalm.*		
polytoma, *Dalm.*		
actinura, *Dalm.*		
Schrops, *Dalm.*		
Schlotheimi, *Bronn.*		
latifer, *Bronn.*		
? æqualis, *Meyer.*		
10. Asaphus corniger, *Al. Br.*	10. Asaphus cordatus, *Al. Br.*	10.
cordiger, *Al. Br.*		
Hausmanni, *Al. Br.*		
de Buchii, *Al. Br.*		
Brongniartii, *Deslongchamps.*		
extenuatus, *Wahl.*		
granulatus, *Wahl.*		
angustifrons, *Dalm.*		
Heros, *Dalm.*		
expansus, *Wahl.*		
platynotus, *Dalm.*		
frontalis, *Dalm.*		
læviceps, *Dalm.*		
palpebrosus, *Dalm.*		
crassacanda, *Wahl.*		
Sultzeri.		
11. Ogygia Guettardii, *Al. Br.*	11.	11.
Desmaresti, *Al. Br.*		
Wahlenbergii, *Al. Br.*		
Sillimani, *Al. Br.*		
12. Paradoxides spinulosus, *Al. Br.*	12. Paradoxicus spinulosus, *A . Br.*	12.
Tessini, *Al. Br.*		
gibbosus, *Al. Br.*		
scaraboides, *Al. Br.*		
Hoffii, *Goldf.*		
13. Nileus Armadillo, *Dalm.*	13.	13.
Glomerinus, *Dalm.*		
14. Illaenus Centaurus, *Dalm.*	14.	14.
centrotus, *Dalm.*		
latecauda, *Wahl.*		
15. Ampyx nasutus, *Dalm.*	15.	15.
16. Olenus Bucephalus, *Wahl.*	16.	16.
17. Agnostus pisiformis, *Al. Br.*	17.	17.
18. Isoletus Gigas, *Dekay.*	18.	18.
planus, *Dekay.*		

Oolite.	Greensand.	Chalk.
on **spinipes**, *Desm.*	7.	7.
longimanatus.		
Walchii, *Holl.*		
modestiformis, *Holl.*		
minutus, *Holl.*		
rostratus, *Phil.*		
	8.	8.
	9.	9.
	10.	10.
	11	11.
	12.	12.
	13.	13.
	14.	14.
	15.	15.
	16.	16.
	17.	17.
	18.	18.

Greywacke.	Coal Formation.	New R
1.	1.	1.
2. Serpula epithonia, *Goldf.* ammonia, *Goldf.* omphalodes, *Goldf.* socialis, *Goldf.*	2. Serpula Lithuus, *Schlot.* compressa, *Sow.*	2. Serpula v c

	Greensand.	Chalk.
inum, *Munst.*	1.	1.
Munst.		
Munst.		
lis, *Munst.*		
ata, *Munst.*		
, *Munst.*		
a, *Bean.*	2. Serpula Carinella, *Sow.*	2. Serpula ampullacea, *Sow.*
hil.	antiquata, *Sow.*	Plexus, *Sow.*
Phil.	rustica, *Sow.*	obtusa, *Sow.*
an.	articulata, *Sow.*	fluctuata, *Sow.*
hil.		? macropus, *Sow.*
aris.		
v.		
Sow.		
Sow.		
Sow.		
Goldf.		
tata, *Munst.*		
ata, *Munst.*		
Munst.		
, *Goldf.*		
ldf.		
ldf.		
Goldf.		
Goldf.		
Munst.		
, *Goldf.*		
oldf.		
nst.		
unst.		
ldf.		
oldf.		
, *Munst.*		
Goldf.		
Goldf.		
laris, *Goldf.*		
a, *Goldf.*		
Sow.		
oldf.		
mis, *Munst.*		
Munst.		
la, *Goldf.*		
, *Goldf.*		
a, *Goldf.*		
Munst.		
a, *Munst.*		
Munst.		
unst.		
nst.		
Munst.		
Munst.		
Munst.		
unst.		
chlot.		
Goldf.		
df.		
ldf.		
ldf.		
ca, *Munst.*		

CL

Greywacke.	Coal Formation.	New Red Sandstone
1.	1.	1.

CLA

Greywacke.	Coal Formation.	New Red Sandsto
1.	1.	1.
2.	2.	2.
3.	3.	3.
4.	4.	4.
5.	5. Mya ? tellinaria. ? ventricosa. ? minuta.	5.
6.	6.	6. Myacites musculoid intermedi elongatus, ventricos
7.	7.	7. Panopæa gibbosa,
8.	8.	8. Axinus obscurus,
9.	9. Saxicava Blainvillii, *Hoen.**	9. Saxicava Blainvillii
10.	10. Hyatella carbonaria.	10.
11.	11.	11.
12.	12.	12.
13.	13.	13.
14.	14.	14.
15.	15.	15.
16.	16. Sanguinolaria gibbosa, *Sow.*	16.
17.	17.	17.
18.	18. Tellina lineata, *Hoen.*	18.
19.	19.	19.
20.	20.	20.
21.	21.	21

RHIPEDA.

Oolite.	Greensand.	Chalk.
	1.	1. Pollicipes sulcatus, *Sow.* maximus, *Sow.*

NCHIFERA.

Oolite.	Greensand.	Chalk.
	1. Fistularia pyriformis, *Mant.*	1.
	2. Teredina personata, *Lam.*	2.
as recondita, *Phil.* ? compressa, *Sow.*	3. Pholas constricta, *Phil.*	3.
rochæna tortuosa, *Sow.*	4.	4.
literata, *Sow.* depressa, *Sow.* calceiformis, *Phil.* dilata, *Phil.* æquata, *Phil.* V scripta, *Sow.* Mandibula, *Sow.* angulifera, *Sow.*	5. Mya mandibula, *Sow.* depressa, *Sow.* phaseolina, *Phil.* plana, *Sow.*	5.
	6.	6.
	7. Panopæa plicata, *Sow.*	7.
	8.	8.
	9.	9.
	10.	10.
raria Jurassi, *Al. Br.*	11. Lutraria Gurgitis, *Al. Br.*	11. Lutraria ? carinifera, *Sow*
tra gibbosa.	12.	12.
	13.	13. Crassatella latissima. tumida.
hidesma decurtatum, *Phil.* recurvum, *Phil.* securiforme, *Phil.* donaciforme, *Phil.* rotundatum, *Phil.*	14.	14.
bula curtansata, *Phil.* depressa, *Phil.* ? cardioides, *Phil.* obscura, *Sow.*	15. Corbula striatula, *Sow.* Punctum, *Phil.* gigantea, *Sow.* lævigata, *Sow.* anatina, *Desh.*	15. Corbula ovalis, *Nils.* caudata, *Nils.*
guinolaria undulata, *Sow.* elegans, *Phil.*	16.	16.
nmobia lævigata, *Phil.*	17.	17.
ina ampliata, *Phil.*	18. Tellina æqualis, *Mant.* inæqualis, *Sow.* striatula, *Sow.*	18.
ax Alduini, *Al. Br.*	19.	19.
astra recondita, *Phil.* oblita, *Phil.*	20.	20.
is lævis, *Sow.* ovalis, *Phil.* uniformis, *Phil.*	21.	21.

Greywacke.	Coal Formation.	New Red Sandsto
22.	22.	22.
23.	23.	23.
24.	24.	24.
25.	25.	25.
26.	26.	26.
27.	27.	27.
28.	28.	28.
29.	29.	29.
30.	30. Cypricardia ? annulata, *Hoen.*	30.
31. Cardium costellatum, *Munst.* hybridum, *Munst.* alæforme, *Sow.** lineare, *Munst.* priscum, *Munst.* striatum, *Munst.*	31. Cardium elongatum, *Sow.* hibernicum, *Sow.* alæforme, *Sow.*	31. Cardium ? striatu
32. Cardita costellata, *Munst.* gracilis, *Munst.* plicata, *Munst.* tripartita, *Munst.*	32.	32.
33. Isocardia Humboldtii, *Hoen.* oblonga, *Sow.*	33.	33.

nd.

Oolite.	Greensand.	Chalk.
ina crassa, *Sow.*	22. Lucina sculpta, *Phil.*	22.
lyrata, *Phil.*		
despecta, *Phil.*		
rte cuneata, *Sow.*	23. Astarte striata, *Sow.*	23.
excavata, *Sow.*		
planata, *Sow.*		
trigonalis, *Sow.*		
orbicularis, *Sow.*		
pumila, *Sow.*		
Voltzii.		
mina ovata, *Sm.*	24.	24.
elegans, *Sow.*		
aliena, *Phil.*		
extensa, *Phil.*		
carinata, *Phil.*		
lurida, *Sow.*		
minima, *Phil.*		
concha crassa, *Sow.*	25.	25.
	26. Cyclas membranacea, *Sow.*	26.
	media, *Sow.*	
	cornea, (*not Lam.*).	
	27. Thetis minor, *Sow.*	27.
	major, *Sow.*	
herea dolabra, *Phil.*	28.	28.
trigonellaris, *Voltz.*		
lucinea, *Voltz.*		
cornea, *Voltz.*		
us varicosa, *Sow.*	29. Venus parva, *Sow.*	29. Venus Ringmeriensis, *Man*
	angulata, *Sow.*	? exerta, *Nils.*
	Faba, *Sow.*	
	ovalis, *Sow.*	
	lineolata, *Sow.*	
	plana, *Sow.*	
	caperata, *Sow.*	
	30.	30.
dium lobatum, *Phil.*	31. Cardium Hillanum, *Sow.*	31. Cardium decussatum, *Sow.*
dissimile, *Sow.*	proboscideum, *Sow.*	
citrinoideum, *Phil.*	bullatum, *Lam.*	
cognatum, *Phil.*		
acutangulum, *Phil.*		
semiglabrum, *Phil.*		
incertum, *Phil.*		
striatulum, *Sow.*		
gibberulum, *Phil.*		
truncatum, *Sow.*		
multicostatum, *Bean.*		
dita similis, *Sow.*	32. Cardita tuberculata, *Sow.*	32. Cardita Esmarkii, *Nils.*
lunulata, *Sow.*		Modiolus, *Nils.*
striata, *Sow.*		crassa.
ardia rhomboidalis, *Phil.*	33.	33.
tumida, *Phil.*		
minima, *Sow.*		
concentrica, *Sow.*		
angulata, *Phil.*		
rostrata, *Sow.*		
striata, *D'Orb.*		

Greywacke.	Coal Formation.	New Red San
34.	34. Hippopodium abbreviatum, *Goldf.*	34.
35.	35.	35.
36.	36. Arca cancellata, *Sow.*	36. Arca tumida,
37.	37.	37.
38.	38.	38. Cucullæa sulcat
39.	39. Nucula attenuata, *Flem.* gibbosa, *Flem.* Palmæ, *Sow.*	39.
40.	40.	40. Trigonia vulgaris, Pes-anse

	Greensand.	Chalk.
lerosum, *Sow.*	34.	34.
hisoni, *Sow.*	35.	35.
il.		
ow.		
il.		
, *Sow.*		
ow.		
'hil.		
v.		
w.		
Br.		
funst.		
a, *Sow.*	36. Arca carinata, *Sow.*	36. Arca exaltata, *Nils.*
		clathrata.
		ovalis, *Nils.*
		subacuta.
nus, *Sow.*	37. Pectunculus sublævis, *Sow.*	37. Pectunculus lens, *Nils.*
gus, *Sow.*	umbonatus, *Sow.*	
, *Sow.*	38. Cucullæa decussata, *Sow.**	38. Cucullæa decussata, *Sow.**
ta, *Phil.*	glabra, *Sow.*	auriculifera.
laris, *Phil.*	carinata, *Sow.*	crassatina.
ta, *Phil.*	fibrosa, *Sow.*	
a, *Sow.*	costellata, *Sow.*	
ia, *Phil.*		
ilis, *Bean.*		
ica, *Phil.*		
ata, *Phil.*		
ita, *Bean.*		
, *Sow.*		
Sow.		
Phil.	39. Nucula pectinata, *Mant.*	39. Nucula ovata, *Nils.*
& B.	ovata, *Mant.*	truncata, *Nils.*
, *Sow.*	impressa, *Sow.*	panda, *Nils.*
a, *Sow.*	subrecurva, *Phil.*	producta, *Nils.*
is, *Phil.*	antiquata, *Sow.*	
ow.	angulata, *Sow.*	
, *Sow.*	undulata, *Sow.*	
is.		
a, *Sow.*		
Sow.	40. Trigonia Dædalea, *Park.*	40. Trigonia pumila, *Nils.*
a, *Sow.*	aliformis, *Sow.*	
ens, *Phil.*	spinosa, *Sow.*	
Sow.	rugosa, *Lam.*	
a, *Sow.*	scabra, *Lam.*	
Y. & B.	eccentrica, *Sow.*	
Sow.	nodosa, *Sow.*	
a, *Sow.*	spectabilis, *Sow.*	
a, *Sow.*	arcuata, *Lam.*	
a, *Sow.*	alata.	
a, *Sow.*		

CONCH

Greywacke.	Coal Formation.	New Red Sandstone
41.	41. Chama ? antiqua, *Hoen.*	41.
42.	42.	42.
43.	43. Mytilus minimus, *Hoen.* crassus, *Flem.*	43. Mytilus eduliformis squamosus,
44.	44.	44.
45. Megalodon cucullatus, *Sow.**	45. Megalodon cucullatus, *Sow.**	45.
46.	46. Modiola Goldfussii, *Hoen.*	46. Modiola acuminata
47.	47. Unio Urii, *Flem.*	47.
48.	48.	48.

tinued.

Oolite.	Greensand.	Chalk.
rigonia Pullus, *Sow.*		
navis, *Lam.*		
incurva, *Benett.*		
ama ? mima, *Phil.*	41.	41. Chama Cornu Arietis,
? crassa, *Sm.*		laciniata, *Nils.*
		recurvata.
oceramus dubius, *Sow.*	42. Inoceramus concentricus,	42. Inoceramus concentricus,
	*Park.**	*P*
	sulcatus, *Park.**	sulcatus, *Park.**
	Cuvieri, *Sow.**	Cuvieri, *Sow.*
	Brongniarti, *Mant.**	Brongniarti, *Ma*
	mytiloides, *Mant.*	mytiloides, *Man*
	rugosus.	cordiformis, *Sow.*
	gryphæoides, *Sow.*	latus, *Mant.*
		Websteri, *Mant.*
		striatus, *Mant.*
		undulatus, *Mant*
		involutus, *Sow.*
		tenuis, *Mant.*
		Cripsii, *Mant.*
ytilus cuneatus, *Phil.*	43. Mytilus lanceolatus, *Sow.*	43. Mytilus lævis, *Defr.*
amplus.	edentulus, *Sow.*	
pectinatus, *Sow.*	problematicus.	
sublævis, *Sow.*		
solenoides.		
	44.	44. Pachymya Gigas, *Sow.*
	45.	45.
odiola imbricata, *Sow.*	46. Modiola æqualis, *Sow.*	46.
ungulata, *Y. & B.*	bipartita, *Sow.*	
bipartita, *Sow.*		
cuneata, *Sow.*		
pulchra, *Sow.*		
plicata, *Sow.*		
aspera, *Sow.*		
Scalprum, *Sow.*		
Hillana, *Sow.*		
lævis, *Sow.*		
depressa, *Sow.*		
minima, *Sow.*		
subcarinata, *Lam.*		
tulipea, *Lam.*		
pallida, *Sow.*		
gibbosa, *Sow.*		
livida, *Goldf.*		
ventricosa, *Goldf.*		
nio peregrinus, *Phil.*	47. Unio porrectus, *Sow.*	47.
abductus, *Phil.*	compressus, *Sow.*	
concinnus, *Sow.*	antiquus, *Sow.*	
crassiusculus, *Sow.*	aduncus, *Sow.*	
Listeri, *Sow.*	cordiformis, *Sow.*	
crassissimus, *Sow.*		
ervillia aviculoides, *Sow.**	48. Gervillia aviculoides, *Sow.**	48. Gervillia solenoides, *Def*
? acuta, *Sow.**	? acuta, *Sow.**	
lata, *Phil.*	solenoides, *Defr.**	
pernoides, *Desl.*		
siliqua, *Desl.*		

CONCH

Greywacke.	Coal Formation.	New Red Sandston
49.	49.	49.
50.	50.	50.
51.	51.	51.
52.	52.	52.
53.	53.	53. Avicula socialis, *D* gryphæoid
54.	54. Vulsella lingulata, *Hoen.* elongata, *Blain.* brevis, *Blain.*	54.
55.	55. Lingula striata.	55.
56.	56.	56.
57.	57.	57.
58.	58.	58.
59.	59.	59.
60.	60.	60.

Oolite.	Greensand.	Chalk.
rvillia monotis, *Desl.*		
costellata, *Desl.*		
ma quadrata, *Sow.*	49.	49.
mytiloides, *Lam.*		
isogonoides.		
natula ventricosa, *Sow.*	50.	50.
igonellites antiquatus, *Phil.*	51.	51.
politus, *Phil.*		
ma lanceolata, *Sow.*	52. Pinna gracilis, *Phil.*	52. Pinna affinis.
mitis, *Phil.*	tetragona, *Sow.*	flabellum.
cuneata, *Bean.*		nobilis.
Folium, *Y. & B.*		restituta.
pinnigena.		subquadrivalvis.
granulata, *Sow.*		
icula expansa, *Phil.*	53.	53. Avicula cærulescens, *Nils.*
ovalis, *Phil.*		
elegantissima, *Bean.*		
tonsipluma, *Y. & B.*		
Braamburiensis, *Sow.*		
inæquivalvis, *Sow.*		
echinata, *Sow.*		
cygnipes, *Y. & B.*		
costata, *Sow.*		
lanceolata, *Sow.*		
ovata, *Sow.*		
	54.	54.
gula Beanii, *Phil.*	55.	55.
catula spinosa, *Sow.*	56. Plicatula pectinoides, *Sow.**	56. Plicatula pectinoides, *Sow.**
		inflata, *Sow.*
	57. Sphæra corrugata, *Sow.*	57.
	58.	58. Podopsis lata, *Mant.*
		obliqua, *Mant.*
		striata, *Sow.*
		truncata, *Lam.*
		lamellosa, *Nils.*
		spinosa.
yphæa chamæformis, *Phil.*	59. Gryphæa auricularis, *Al. Br.**	59. Gryphæa auricularis, *Al. Br.**
bullata, *Sow.*	Columba, *Lam.**	Columba, *Lam.**
inhærens, *Phil.*	plicata, *Lam.**	plicata, *Lam.**
dilatata, *Sow.*	vesiculosa, *Sow.*	truncata, *Goldf.*
incurva, *Sow.*	sinuata, *Sow.*	
nana, *Sow.*	Aquila, *Al. Br.*	
Macculochii, *Sow.*	secunda.	
depressa, *Phil.*	canaliculata, *Sow.*	
obliquata, *Sow.*		
Cymbium, *Lam.*		
lituola, *Lam.*		
gigantea, *Sow.*		
minuta, *Sow.*		
virgula, *Defr.*		
	60. Exogyra haliotidea, *Sow.**	60. Exogyra haliotidea, *Sow.**
	conica, *Sow.**	conica, *Sow.**
	digitata, *Sow.*	
	undata, *Sow.*	
	lævigata, *Sow.*	

Greywacke.	Coal Formation.	New
61.	61. Ostrea prisca, *Hoen.*	61. Ostrea s
62.	62. Hinnites Blainvillii, *Hoen.*	62.
63.	63.	63.
64.	64.	64. Plagiost
65. Posidonia Becheri, *Bronn.*	65.	65. Posidoni
66.	66.	66.
67. Pecten primigenius, *Meyer.* Munsteri, *Meyer.*	67. Pecten papyraceus, *Sow.* dissimilis, *Flem.* priscus, *Schlot.* granosus, *Sow.* plicatus, *Sow.*	67. Pecten r

	Greensand.	Chalk.
, *Sow.*	61. Ostrea carinata, *Lam.**	61. Ostrea carinata, *Lam.**
Sow.	serrata, *Defr.**	serrata, *Defr.**
la, *Bean.*	parasitica.	vesicularis, *Lam.*
s, *Phil.*	truncata.	semiplana, *Mant.*
Bean.	biauricularis.	canaliculata, *Sow.*
a, *Phil.*		lateralis, *Nils.*
Sow.		clavata, *Nils.*
, *Phil.*		Hippopodium, *Nils.*
ı, *Sm.*		curvirostris, *Nils.*
Sow.		acutirostris, *Nils.*
ı, *Sow.*		flabelliformis, *Nils.*
ta, *Sow.*		pusilla, *Nils.*
Sow.		lunata, *Nils.*
Desl.		incurva, *Nils.*'
.		? plicata, *Nils.*
Sow.		
a.		
ı.		
les, *Lam.*		
la, *Sow.*		
Sow.		
Sow.		
	62.	62. Hinnites ? Dubuissoni.
	63. Spondylus ? strigilis, *Al. Br.*	63.
iusculum, *Sow.*	64. Plagiostoma spinosum, *Sow.**	64. Plagiostoma spinosum, *Sow.**
ı, *Sow.*	turgidum, *Lam.**	turgidum, *Lam.**
ides, *Sow.**	pectinoïdes, *Sow.**	Hoperi, *Mant.*
n, *Sow.*		Brightoniensis, *Mant.*
tum, *Sow.*		elongatum, *Sow.*
ım, *Phil.*		asperum, *Mant.*
nctum, *Phil.*		ovatum, *Nils.*
rme, *Sow.*		semisulcatum, *Nils.*
um, *Sow.*		Mantelli, *Al. Br.*
ım, *Sow.*		granulatum, *Nils.*
um, *Sow.*		elegans, *Nils.*
m.		pusillum, *Nils.*
Sow.		denticulatum, *Nils.*
nni, *Voltz.*		
.tum, *Sow.*		
statum, *Sow.*		
tricum, *Sow.*		
ıni, *Goldf.*	65.	65.
w.	66.	66. Lima pectinoides.
lea, *Sow.*		
Sow.		
ı, *Sow.*		
, *Phil.*	67. Pecten quinquecostatus, *Sow.**	67. Pecten quinquecostatus, *Sow.**
ostatus, *Phil.*	orbicularis, *Sow.**	orbicularis, *Sow.**
tus, *Bean.*	quadricostatus, *Sow.**	quadricostatus, *Sow.**
s, *Sow.**	arcuatus, *Sow.**	arcuatus, *Sow.**
s, *Phil.*	asper, *Lam.**	asper, *Lam.**
ow.	nitidus, *Sow.**	nitidus, *Sow.**
Sow.	obliquus, *Sow.*	Beaveri, *Sow.*
, *Sow.*	asperrimus.	triplicatus, *Mant.*
er, *Phil.*	gryphæatus.	cretosus, *Defr.*
s, *Y. & B.*	sulcatus, *Sow.*	arachnoides, *Defr.*
lvis, *Sow.*	versicostatus.	extextus, *Al. Br.*
ms, *Sow.*		serratus, *Nils.*

CONC

Greywacke.	Coal Formation.	New Red Sandstone
68.	68. Crania prisca, _Hoen._	68.
69.	69.	69.
70.	70.	70.
71.	71.	71.
72. Strygocephalus Burtini, _Defr._ elongatus, _Goldf._	72.	72.
73. Calceola sandalina, _Lam._ heteroclita, _Defr._	73.	73.
74. Strophomena Goldfussii, _Hoen._ rugosa, _Raf._ euglypha, _Hoen._ pileopsis, _Raf._ umbraculum, _Schlot._ marsupita, _Defr._	74.	74.
75. Terebratula lacunosa, _Schlot._* lævigata, _Schlot._* elongata, _Schlot._* intermedia, _Lam._* acuminata, _Sow._* crumena, _Sow._* monticulata, _Schlot._* Sacculus, _Sow._*	75. Terebratula lacunosa, _Schlot._* lævigata, _Schlot._* resupinata, _Sow._ vestita, _Schlot._ acuminata, _Sow._* crumena, _Sow._* monticulata, _Schlot._* Sacculus, _Sow._*	75. Terebratula lacunosa inflata, _Sch_ elongata, _S_ intermedia, perovalis. sufflata. vulgaris, _Sc_ orbiculata,

Oolite.	Greensand.	Chalk.
milis, *Sow.*		Pecten septemplicatus, *Nils.*
minatus, *Sow.*		multicostatus, *Nils.*
arbatus, *Sow.*		undulatus, *Nils.*
imineus, *Sow.*		subaratus, *Nils.*
bscurus, *Sow.*		pulchellus, *Nils.*
nnulatus, *Sow.*		lineatus, *Nils.*
ncinnus.		virgatus, *Nils.*
arginatus.		membranaceus, *Nils.*
		lævis, *Nils.*
		inversus, *Nils.*
		regularis, *Schlot.*
		corneus, *Sow.*
		dentatus, *Nils.*
	68.	68. Crania Parisiensis, *Defr.*
		antiqua, *Defr.*
		striata, *Defr.*
		stellata, *Defr.*
		spinulosa, *Nils.*
		tuberculata, *Nils.*
		Nummulus, *Lam.*
reflexa, *Sow.*	69.	69.
radiata, *Phil.*		
granulata, *Sow.*		
	70.	70. Hippurites radiosa, *Des M.*
		Cornu Pastoris, *Des M.*
		striata, *Defr.*
		sulcata, *Defr.*
		dilatata, *Defr.*
		bioculata, *Lam.*
		Fistulæ, *Defr.*
	71.	71. Sphærulites dilatata, *Des M.*
		Bournonii, *Des M.*
		ingens, *Des M.*
		Hoeninghausii, *Des M.*
		foliacea, *Lam.*
		Jodamia, *Des M.*
		Jouanettii, *Des M.*
		crateriformis, *Des M.*
		Moulinii, *Goldf.*
	72.	72.
	73.	73.
	74.	74.
la subrotunda, *Sow.**	75. Terebratula subrotunda, *Sow.**	75. Terebratula subrotunda, *Sow.**
lobata, *Sow.*	carnea, *Sow.**	carnea, *Sow.**
rnithocephala, *Sow.*	ovata, *Sow.**	ovata, *Sow.**
vata, *Sow.*	plicatilis, *Sow.**	plicatilis, *Sow.**
bsoleta, *Sow.*	subundata, *Sow.**	subundata, *Sow.**
rumena, *Sow.**	Defrancii, *Al. Br.*	Defrancii, *Al. Br.**
voides, *Sow.*	octoplicata, *Sow.**	octoplicata, *Sow.**
ligona, *Sow.*	Gallina, *Al. Br.**	Gallina, *Al. Br.**

Greywacke.	Coal Formation.	New Red
ratula Wilsoni, *Sow.**	Terebratula Wilsoni, *Sow.**	Terebratula
Mantiæ, *Sow.**	Mantiæ, *Sow.**	par
cordiformis, *Sow.**	cordiformis, *Sow.**	pel
platyloba, *Sow.**	platyloba, *Sow.**	pyg
Pugnus, *Sow.**	Pugnus, *Sow.**	
reniformis, *Sow.**	reniformis, *Sow.**	
lateralis, *Sow.**	lateralis, *Sow.**	
rostrata, *Schlot.*	hastata, *Sow.*	
prisca, *Schlot.*	cuneata, *Dalm.*	
affinis, *Sow.*	diodonta, *Dalm.*	
plicatella, *Linn.*	bidentata, *His.*	
osteolata, *Schlot.*	marginalis, *Dalm.*	
aperturata, *Schlot.*	didyma, *Dalm.*	
lenticularis, *Wahl.*	affinis, *Sow.*	
alata, *Lam.*	? lineata, *Sow.*	
aspera, *Schlot.*	? imbricata, *Sow.*	
comprimata, *Schlot.*	Fimbria, *Sow.*	
curvata, *Schlot.*		
excisa, *Schlot.*		
explanata, *Schlot.*		
imbricata, *Sow.*		
speciosa, *Schlot.*		
hysterolita, *Hoen.*		
paradoxa, *Hoen.*		
	76.	76.
	77. Pentamerus Aylesfordii, *Sow.*	77.
	Knightii, *Sow.*	
	lævis, *Sow.*	
	78. Læptæna rugosa, *His.*	78.
	depressa, *Sow.*	

	Greensand.	Chalk.
	Terebratula pectita, *Sow.**	Terebratula pectita, *Sow.**
d & Sm.	semiglobosa, *Sow.**	semiglobosa, *Sow.**
. & B.	dissimilis, *Schlot.**	dissimilis, *Schlot.**
.	lata, *Sow.**	lata, *Sow.**
	tetraedra, *Sow.**	elongata, *Sow.*
*ow.**	dimidiata, *Sow.**	subplicata, *Mant.*
*ow.**	inconstans, *Sow.**	curvirostris, *Nils.*
*Sow.**	Lyra, *Sow.*	Mantelliana, *Sow.*
Sow.	obtusa, *Sow.*	Martini, *Mant.*
w.	curvata, *Schlot.*	rostrata, *Sow.*
ow.	lacunosa, *Schlot.*	squamosa, *Mant.*
	nucleus, *Defr.*	undata, *Sow.*
.	ovoidea, *Sow.*	alata, *Lam.*
w.	semistriata, *Lam.*	recurva, *Defr.*
w.	striatula, *Sow.*	lævigata, *Nils.*
	biplicata, *Sow.*	triangularis, *Wahl.*
ark.	lineolata, *Phil.*	longirostris, *Wahl.*
ow.	ornithocephala, *Sow.*	rhomboidalis, *Nils.*
.		obesa, *Sow.*
w.		aperturata, *Schlot.*
ow.		chrysalis, *Schlot.*
ow.		microscopica, *St. F.*
.		peltata.
, *Sow.*		varians.
Sow.		vermicularis, *Schlot.*
		minor, *Nils.*
Lam.		pulchella, *Nils.*
ow.		costata, *Nils.*
ow.		Lens, *Nils.*
ow.		depressa, *Lam.*
v.		
Sow.		
a, *Sow.*		
a, *Schlot.*		
hlot.		
, *Schlot.*		
hlot.		
n.		
chlot.		
Sow.		
hlot.		
ll. Br.		
sii, *Blain.*		
Dufr.		
Buch.		
a, *Sow.*		
v.		
unst.		
	76.	76. Magas pumilus, *Sow.*
	77.	77.
	78.	78.

CONC

Greywacke.	Coal Formation.	New Red Sandston
	Læptæna ruglypha, *Dalm.*	
	transversalis, *Wahl.*	
79.	79. Orthis Pecten, *Dalm.*	79.
	striatella, *Dalm.*	
	basalis, *Dalm.*	
	elegantula, *Dalm.*	
80.	80. Atrypa reticularis, *Wahl.*	80.
	alata, *His.*	
	aspera, *Schlot.*	
	galeata, *Dalm.*	
	Prunum, *Dalm.*	
	tumida, *Dalm.*	
81.	81. Gypidium Conchydium.	81.
82.	82. Cyrtia exporrecta, *Wahl.*	82.
	trapezoidalis, *His.*	
83. Thecidea ? antiqua, *Hoen.*	83.	83.
84. Producta longispina, *Sow.**	84. Producta longispina, *Sow.**	84. Producta longispin
rostrata, *Sow.*	rugosa, *Schlot.**	rugosa,
depressa, *Sow.*	antiquata, *Sow.**	antiquat
hemisphærica, *Sow.*	spinosa, *Sow.**	spinosa,
Scotica, *Sow.**	Scotica, *Sow.**	aculeata,
Martini, *Sow.**	Martini, *Sow.*	spiluncar
concinna, *Sow.**	concinna, *Sow.**	calva, *S*
lobata, *Sow.**	lobata, *Sow.**	
punctata, *Sow.**	punctata, *Sow.**	
sulcata, *Sow.**	sulcata, *Sow.**	
sarcinulata, *Goldf.**	sarcinulata, *Goldf.**	
fimbriata, *Sow.**	fimbriata, *Sow.*	
	comoides, *Sow.*	
	fornicata.	
	humerosa, *Sow.*	
	latissima, *Sow.*	
	personata, *Sow.*	
	plicatilis, *Sow.*	
	spinulosa, *Sow.*	
	transversa.	
	Flemingii, *Sow.*	
	crassa, *Flem.*	
	aculeata, *Sow.*	
	scabricula, *Sow.*	
	gigantea, *Sow.*	
	costata, *Sow.*	
	depressa.	
85.	85. Delthyris elevata, *Dalm.*	85.
	cyrtæna, *Dalm.*	
	crispa, *Dalm.*	
	sulcata, *His.*	
	ptycodes, *Dalm.*	
	cardiospermiformis, *His.*	
86. Spirifer speciosus, *Sow.*	86. Spirifer trigonalis, *Sow.**	86. Spirifer trigonalis,
ambiguus, *Sow.**	ambiguus, *Sow.**	undulatus,
glaber, *Sow.**	glaber, *Sow.**	multiplica
obtusus, *Sow.**	obtusus, *Sow.**	minutus.
pinguis, *Sow.**	rotundatus, *Sow.**	
attenuatus, *Sow.**	attenuatus, *Sow.**	
distans, *Sow.**	distans, *Sow.**	

ued.

Oolite.	Greensand.	Chalk.
	79.	79.
	80.	80.
	81.	81.
	82.	82.
	83.	83. Thecidea radians, *Defr.* recurvirostra, *Defr* hieroglyphica, *Def*
	84.	84.
yris verrucosa, *V. Buch.* rostrata, *Schlot.*	85.	85.
fer Walcotii, *Sow.*	86.	86.

CONCH

Greywacke.	Coal Formation.	New Red Sandston
Spirifer minimus, _Sow._*	Spirifer octoplicatus, _Sow._*	
cuspidatus, _Sow._*	cuspidatus, _Sow._	
decurrens, _Sow._	oblatus, _Sow._	
Sowerbii.	plicatus, _Hoen._	
lineatus, _Sow._	trigonalis, _Sow._	
rotundatus, _Sow._	triangularis, _Sow._	
sarcinulatus, _Schlot._	striatus, _Sow._	
alatus, _Sow._	resupinatus, _Sow._	
intermedius, _Schlot._	Martini, _Sow._	
speciosus, _Bronn._	Urii, _Flem._	
	exaratus, _Flem._	
	bisulcatus, _Sow._	

CLAS

Greywacke.	Coal Formation.	New Red Sandsto
1.	1.	1. Dentalium torquatu læve, _Sch_
2.	2.	2.
3. Patella ? conica, _Wahl._ pennicostis, _Wahl._ concentrica, _Wahl._	3. Patella Primigenus, _Schlot._	3.
4. Pileopsis vetusta, _Sow._	4.	4.
5.	5.	5.
6.	6.	6.
7.	7. Helix ? cirriformis, _Sow._	7.
8.	8.	8.
9.	9.	9.
10.	10. Planorbis æqualis, _Sow._	10.
11. Melania bilineata, _Goldf._ constricta, _Sow._	11. Melania bilineata, _Goldf._ constricta, _Sow._	11.
12. Melanopsis coronata, _Hoen._	12. Melanopsis coronata, _Hoen._	12.
13.	13. Ampullaria helicoides, _Sow._ nobilis, _Sow._	13.
14.	14.	14.
15. Nerita spirata ? _Sow._	15. Nerita striata, _Flem._ spirata, _Sow._	15.
16.	16. Natica elongata, _Hoen._ Gaillardotii.	16. Natica Gaillardotii.

ed.

Oolite.	Greensand.	Chalk.

LLUSCA.

Oolite.	Greensand.	Chalk.
lium giganteum, *Phil.*	1. Dentalium striatum, *Sow.*	1. Dentalium nitens.
cylindricum, *Sow.*	ellipticum, *Sow.*	
	decussatum, *Sow.*	
	fissura, *Lam.*	
elongata, *Phil.*	2.	2.
la latissima, *Sow.*	3.	3. Patella ovalis, *Nils.*
rugosa, *Sow.*		
lævis, *Sow.*		
lata, *Sow.*		
ancyloides, *Sow.*		
nana, *Sow.*		
discoides, *Schlot.*		
	4.	4.
us plicatus, *Sow.*	5.	5.
ginula scalaris, *Sow.*	6.	6.
	7. Helix Gentii, *Sow.*	7.
na polita, *Sow.*	8.	8.
compressa, *Sow.*		
expansa, *Sow*		
solarioides, *Sow.*		
ula Sedgewickii, *Phil.*	9. Auricula incrassata, *Sow.*	9. Auricula incrassata, *Sow.*
	turgida, *Sow.*	obsoleta, *Phil.*
	10.	10.
aHeddingtoniensis, *Sow.*	11. Melania attenuata.	11.
striata, *Sow.*	triannata.	
vittata, *Phil.*		
lineata, *Sow.*		
	12.	12.
	13. Ampullaria canaliculata, *Montf.*	13. Ampullaria spirata.
	14. Paludina vivipara, *Lam.* ?	14.
	elongata, *Sow.*	
	carinfera, *Sow.*	
	extensa, *Sow.*	
costata, *Sow.*	15.	15. Nerita rugosa.
sinuosa, *Sow.*		
lævigata, *Sow.*		
minuta, *Sow.*		
arguta, *Sm.*	16. Natica canrena, *Park.*	16.
nodulata, *Y. & B.*	spirata.	

Greywacke.	Coal Formation.	New Red Sandsto
	Natica globosa.	
17.	17.	17.
18.	18.	18.
19. Delphinula æquilatera, *Wahl.*	19. Delphinula æquilatera, *Wahl.* canalifera. alata, *Wahl.* catenulata, *Wahl.* Cornu Arietis, *Wahl.* funata, *œow.* subsulcata, *His.* tuberculata, *Flem.*	19.
20.	20. Pyramidella antiqua, *Hoen.*	20.
21.	21.	21.
22. Cirrus acutus, *Sow.*	22. Cirrus acutus, *Sow.* rotundatus, *Sow.*	22.
23. Euomphalus catillus, *Sow.* dubius, *Goldf.* funatus.	23. Euomphalus catillus, *Sow.* nodosus, *Sow.* angulosus, *Sow.* delphinularis, *Hoen.* pentangulatus, *Sow.* coronatus. rotundatus. rugosus, *Sow.* discus, *Sow.* centrifugus, *Wahl.* angulatus, *Wahl.* substriatus, *His.* costatus, *His.*	23.
24. Solarium fasciatum.	24.	24.
25. Trochus catenulatus.	25. Trochus catenulatus.	25.

ued.

Oolite.	Greensand.	Chalk.
a cincta, *Phil.*		
adducta, *Phil.*		
	17.	17. Sigaretus concavus.
metus compressus, *Y. & B.*	18. Vermetus polygonalis, *Sow.*	18. Vermetus umbonatus, *Man*
Nodus, *Phil.*	concavus, *Sow.*	Sowerbii, *Mant.*
	19.	19.
	20.	20.
on retusus, *Phil.*	21.	21.
glaber, *Bean.*		
humeralis, *Phil.*		
cuspidatus, *Sow.*		
acutus, *Sow.*		
rus cingulatus, *Phil.*	22. Cirrus plicatus, *Sow.*	22. Cirrus depressus, *Mant.*
depressus, *Sow.*		perspectivus, *Mant.*
nodosus, *Sow.*		granulatus, *Mant.*
Leachii, *Sow.*		
carinatus, *Sow.*		
	23.	23.
rium Calyx, *Bean.*	24.	24.
conoideum, *Sow.*	25. Trochus agglutinans, *Lam.*	25. Trochus Basteroti, *Al. Br.*
chus arenosus, *Sow.*	Gurgitis, *Al. Br.*	linearis, *Mant.*
tornatilis, *Phil.*	Rhodani, *Al. Br.*	Rhodani, *Al. Br.*
Tiara, *Sow.*	Cirroides, *Al. Br.*	lævis, *Nils.*
guttatus, *Phil.*		onustus, *Nils.*
monilitectus, *Phil.*		
pyramidatus, *Bean.*		
Anglicus, *Sow.*		
angulatus, *Sow.*		
dimidiatus, *Sow.*		
duplicatus, *Sow.*		
elongatus, *Sow.*		
punctatus, *Sow.*		
abbreviatus, *Sow.*		
fasciatus, *Sow.*		
prominens, *Sow.*		
imbricatus, *Sow.*		
reticulatus, *Sow.*		

Greywacke.	Coal Formation.	New Red Sandst
26. Turbo Tiara, *Sow.* antiquus, *Goldf.* cirriformis, *Sow.* bicarinatus, *Wahl.*	26. Turbo Tiara, *Sow.* carinatus, *Hoen.* helicinæformis. striatus, *Hoen.*	26.
27.	27.	27.
28. Turritella abbreviata, *Sow.* prisca, *Munst.*	28. Turitella Urii, *Flem.* elongata, *Flem.* cingulata, *His.* constricta, *Flem.*	28. Turritella terebr Schlot
29.	29.	29.
30.	30.	30.
31. Pleurotoma cirriforme.	31. Pleuromoma delphinulatum.	31.
32.	32.	32.
33. Murex Harpula, *Sow.*	33.	33.
34.	34.	34.
35.	35.	35.
36.	36.	36.
37.	37.	37.
38.	38.	38.
39.	39.	39.
40.	40.	40.
41. Buccinum spinosum, *Sow.* acutum, *Sow.* breve, *Sow.* imbricatum, *Sow.*	41. Buccinum arculatum, *Schlot.* subcostatum, *Schlot.* cribrarium, *Hoen.* lævissimum. acutum, *Sow.*	41. Buccinum obsolet
42. Terebra Hennahiana, *Sow.*	42.	42.
43.	43.	43.
44. Bellerophon hiulcus, *Sow.* apertus, *Sow.* tenuifascia, *Sow.* costatus, *Sow.* Cornu Arietis, *Sow.* ovatus, *Sow.* Hüpschii, *Defr.*	44. Bellerophon hiulcus, *Sow.* apertus, *Sow.* tenuifascia, *Sow.* costatus, *Sow.* Cornu Arietis, *Sow.* decussatus, *Flem.* striatus, *Flem.*	44.

Oolite.	Greensand.	Chalk.
rugatus, *Benett.*		
speciosus, *Munst.*		
nuricatus, *Sow.*	26. Turbo monilifer, *Sow.*	26. Turbo pulcherrimus, *Bean.*
uniculatus, *Phil.*	carinatus, *Sow.*	sulcatus, *Nils.*
ulcostomus, *Phil.*		
micarinatus, *Bean.*		
ævigatus, *Phil.*		
ndulatus, *Phil.*		
rnatus, *Sow.*		
btusus, *Sow.*		
ella cincta, *Phil.*	27.	27.
lla muricata, *Sow.*	28. Turritella terebra, *Broc.*	28. Turritella duplicata.
cingenda, *Sow.*		
4 vittata, *Phil.*		
concava, *Sow.*		
echinata, *V. Buch.*		
ævis, *Sow.*	29.	29.
cuta, *Sow.*		
bliquata, *Sow.*		
luplicata, *Sow.*		
m intermedium.	30. Cerithium excavatum, *Al. Br.*	30.
muricatum.		
ma conoideum, *Desh.*	31.	31.
ornatum, *Defr.*		
tuberculata, *Blain.*	32.	32.
Mosæ, *Desh.*		
Vaccanensis, *Phil.*	33. Murex Calcar, *Sow.*	33.
llariformis, *V. Buch.*		
ria bispinosa, *Phil.*	34. Rostellaria carinata, *Mant.*	34. Rostellaria anserina, *Nils.*
trifida, *Bean.*	Parkinsoni, *Mant.*	Parkinsoni, *Mant*
composita, *Sow.*	fissura, *Lam.*	composita, *Sow.*
	calcarata, *Sow.*	
ras Oceani, *Al. Br.*	35.	35. Pteroceras maxima, *Hoen.*
Ponti, *Al. Br.*		
Pelagi, *Al. Br.*		
	36.	36. Strombus papilionatus.
	37. Fusus quadratus, *Sow.*	37.
	38. Pyrula minima, *Hoen.*	38. Pyrula planulata, *Nils.*
	39.	39. Dolium nodosum, *Sow.*
	40.	40. Cassis avellana, *Al. Br.*
m unilineatum, *Sow.*	41.	41.
melanioides, *Phil.*	42.	42.
granulata, *Phil.*		
vetusta, *Phil.*		
sulcata.		
	43.	43. Voluta ambigua, *Sow.*
		Lamberti, *Sow.*
	44.	44.

MOL

Greywacke.	Coal Formation.	New Red Sandston
Bellerophon nodulosus, *Goldf.*	Bellerophon depressus, *Montf.* Urii, *Flem.* vasulites, *Montf.*	
45. Nautilus globatus, *Sow.* multicarinatus, *Sow.* complanatus, *Sow.* carinifer, *Sow.* divisus, *Munst.* funatus, *Flem.* compressus, *Flem.* ovatus, *Flem.*	45. Nautilus globatus, *Sow.* discus, *Sow.* ingens. marginatus, *Flem.* quadratus, *Flem.* biangulatus, *Flem.* sulcatus, *Sow.* Woodwardii, *Sow.* excavatus, *Flem.* bilobatus. pentagonus.	45. Nautilus bidorsatus, nodosus,
46.	46.	46.
47. Cyrtoceratites ammonius, *Goldf.* compressus, *Goldf.* depressus, *Goldf.* ornatus, *Goldf.*	47.	47.
48.	48.	48.
49. Ammonites Henslowi, *Sow.* subnautilinus, *Schlot.*	49. Ammonites Listeri, *Sow.* primordialis, *Sow.* sacer. subcrenatus, *Schlot.* Diadema, *De Haan.* sphæricus, *Sow.* Dalmanni, *His.* striatus, *Sow.*	49. Ammonites nodosu bipartitu latus, *M* subnodos

inued.

Oolite.	Greensand.	Chalk.
atilus hexagonus, *Sow.* lineatus, *Sow.* astacoides, *Y. & B.* annularis, *Phil.* obesus, *Sow.* sinuatus, *Sow.* intermedius, *Sow.* striatus, *Sow.* truncatus, *Sow.* angulosus, *D'Orb.*	45. Nautilus inæqualis, *Sow.* simplex, *Sow.* undulatus, *Sow.*	45. Nautilus elegans, *Sow.* expansus, *Sow.* obscurus, *Nils.* aperturatus.
	46. Nummulites lenticulina.	46. Nummulites lenticulina. Faujasii.
	47.	47.
hites bifurcatus, *Hart.*	48.	48. Scaphites striatus, *Mant.* costatus, *Mant.*
onites perarmatus, *Sow.* gagateus, *Y. & B.* planicostatus, *Sow.* balteatus, *Phil.* arcigerens, *Phil.* brevispina, *Sow.* Jamesoni, *Sow.* erugatus, *Bean.* fimbriatus, *Sow.* Rotula, *Sow.** nitidus, *Y. & B.* angulifer, *Phil.* crenularis, *Phil.* Cleavelandicus, *Y. & B.* Turneri, *Sow.* plicomphalus, *Sow.* triplicatus, *Sow.* plicatilis, *Sow.* Williamsonii, *Phil.* Sutherlandii, *Sow.* sublævis, *Sow.* lenticularis, *Phil.* vertebratus, *Sow.* cordatus, *Sow.* instabilis, *Phil.* solaris, *Phil.* oculatus, *Phil.* Vernoni, *Bean.* Athleta, *Phil.* Koenigi, *Sow.* bifrons, *Phil.* Gowerianus, *Sow.* Calloviensis, *Sow.* Duncani, *Sow.* gemmatus, *Phil.*	49. Ammonites varians, *Sow.** planulatus, *Sow.* Catillus, *Sow.* splendens, *Sow.* auritus, *Sow.* planus, *Mant.* rusticus, *Sow.* lautus, *Park.* Mantelli, *Sow.* Rotula, *Sow.** venustus, *Phil.* concinnus, *Phil.* trisulcosus, *Phil.* marginatus, *Phil.* hystrix, *Phil.* fissicostatus, *Phil.* curvinodus, *Phil.* inflatus, *Sow.* Deluci, *Al. Br.* subcristatus, *De L.* Beudanti, *Al. Br.* clavatus, *De L.* Selliguinus, *Al. Br.* Gentoni, *Defr.* varicosus, *Sow.* Benettianus, *Sow.* denarius, *Sow.* Buchii, *Hoen.* ornatus.	49. Ammonites varians, *Sow.* Woolgari, *Mant.* navicularis, *Mant.* catinus, *Mant.* Lewesiensis, *Mant.* peramplus, *Mant.* rusticus, *Sow.** undatus, *Sow.* Mantelli, *Sow.** Rhotomagensis, *Al. Br.* cinctus, *Mant.* falcatus, *Mant.* curvatus, *Mant.* complanatus, *Mant.* rostratus, *Sow.* tetrammatus, *Sow.* constrictus, *Sow.* Stobæi, *Nils.* Hippocastanum, *Sow.* Nutfieldiensis, *Sow.*

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Greywacke.	Coal Formation.	New Red Sandston

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Greywacke.	Coal Formation.	New Red Sandst

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Greywacke.	Coal Formation.	New Red Sandston
50.	50.	50.
51.	51.	51.
52. Conularia quadrisulcata, *Mill.**	52. Conularia quadrisulcata, *Mill.**	52.
teres, *Sow.**	teres, *Sow.*	
pyramidata.		
53. Lituites perfectus, *Wahl.*	53.	53.
imperfectus, *Wahl.*		
54.	54.	54.
55.	55.	55.
56.	56.	56.
57. Orthocera cundulata, *Sow.**	57. Orthocera undulata, *Sow.**	57.
annulata, *Sow.**	annulata, *Sow.**	
paradoxica, *Sow.**	paradoxica, *Sow.**	
crassiventer, *Wahl.**	crassiventris, *Wahl.**	
Steinhaueri, *Sow.**	Steinhaueri, *Sow.**	
striata, *Sow.*	angularis, *Flem.*	
circularis, *Sow.*	rugosas, *Flem.*	
flexuosa, *Schlot.*	annularis, *Flem.*	
communis, *Wahl.*	convexa, *Flem.*	
duplex, *Wahl.*	pyramidalis, *Flem.*	
trochlearis, *Dalm.*	lævis, *Flem.*	
turbinata, *Dalm.*	undulata, *His.*	
centralis, *Dalm.*	Breynii, *Sow.*	
gracilis, *Schlot.*	fusiformis, *Sow.*	
falcata.	cinctas, *Sow.*	
tenuis, *Wahl.*	imbricatas, *Wahl.*	
recta, *Bosc.*	angulata, *Wahl.*	

e.	Greensand.	Chalk.
bius, *Schlot.*		
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ostatus, *Ziet.*		
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nterruptus, *Schüb.*		
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li, *Al. Br.**	50. Turrilites Babeli, *Al. Br.**	50. Turrilites costatus, *Sow.*
	Bergeri, *Al. Br.*	undulatus, *Sow.*
		tuberculatus, *Sow.*
	51.	51. Baculites Faujasii, *Lam.*
		obliquatus, *Sow.*
		vertebralis, *Defr.*
		anceps, *Lam.*
		triangularis, *Desm.*
	52.	52.
	53.	53. Lituites nautiloideus, *Lam.*
		difformis, *Lam.*
	54. Lenticulites Comptoni, *Sow.*	54. Lenticulites cristella, *Nils.*
	55. Nodosaria sulcata, *Nils.**	55. Nodosaria sulcata, *Nils.**
	lævigata, *Nils.*	
	56.	56. Planularia elliptica, *Nils.*
		augusta, *Nils.*
gata, *De la B.*	57.	57.

MOLI

Greywacke.	Coal Formation.	New Red Sandstone.
Orthocera regularis, *Schlot.* exceptica, *Goldf.* striolaris, *Meyer.* acuaria, *Munst.* striopunctata, *Munst.* cingulata, *Munst.* torquata, *Munst.* carnata, *Munst.* linearis, *Munst.* irregularis, *Munst.*	Orthocera lineata, *His.* Gesneri. cylindracea, *Flem.* attenuata, *Flem.* sulcata, *Flem.* undata, *Flem.* cordiformis. gigantea.	
58.	58.	58.
59.	59.	59. Belemnites Aalensis,

.	Greensand.	Chalk.
tus, *Desh.*	58. Hamites maximus, *Sow.*	58. Hamites armatus, *Sow.*
	intermedius, *Sow.*	plicatilis, *Mant.*
	alternatus, *Mant.**	alternatus, *Mant.**
	attenuatus, *Sow.**	attenuatus, *Sow.**
	tenuis, *Sow*	ellipticus, *Mant.*
	rotundus, *Sow.*	cylindricus, *Defr.*
	compressus, *Sow.*	
	raricostatus, *Phil.*	
	Beanii, *Y. & B.*	
	Philipsii, *Bean.*	
	funatus, *Al. Br.*	
	canteriatus, *Al. Br.*	
	virgulatus, *Al. Br.*	
	spinulosus, *Sow.*	
	grandis, *Sow.*	
	Gigas, *Sow.*	
	spiniger, *Sow.*	
ensis, *Voltz.**	59. Belemnites mucronatus, *Schlot.**	59. Belemnites mucronatus, *Schlot.**
Mill.		
, *Mill.*	minimus, *List.*	granulatus, *Defr.*
Phil.	attenuatus, *Sow.*	lanceolatus, *Schlot.*
ehl.		mamillatus, *Nils.*
us, *Mill.*		
, *Mill.*		
s, *Blain.*		
s, *Blain.*		
atus, *Blain.*		
nis, *Blain.*		
lain.		
us, *Mill.*		
tus, *Schlot.*		
Mill.		
oltz.		
, *Mill.*		
us, *Voltz.*		
ahl.		
sus, *Voltz.*		
atus, *Voltz.*		
Biguet.		
is, *Voltz.*		
nus, *Voltz.*		
, *Schlot.*		
tus, *Voltz.*		
Voltz.		
tus, *Voltz.*		
Schüb.		
lcatus, *Blain.*		

MO

Greywacke.	Coal Formation.	New Red Sandsto
60.	60.	60.
61.	61.	61.
62.	62.	62.
63.	63.	63.
64.	64.	64.

nued.

Oolite.	Greensand.	Chalk.
mnites tumidus, *Ziet.*		
acutus, *Blain.*		
teres, *Stahl.*		
lævigatus, *Ziet.*		
crassus, *Voltz.*		
semihastatus, *Blain.*		
incurvatus, *Ziet.*		
pyramidatus, *Schüb.*		
rostratus, *Ziet.*		
irregularis, *Schlot.*		
papillatus, *Plien.*		
acuminatus, *Schüb.*		
subhastatus, *Ziet.*		
canaliculatus, *Schlot.*		
oxyconus, *Heyl.*		
carinatus, *Heyl.*		
pygmæus, *Ziet.*		
consulcatus, *Hart.*		
quadrisulcatus, *Hart.*		
pyramidalis, *Munst.*		
bipartitus, *Hart.*		
unicanaliculatus, *Hart.*		
2-canaliculatus, *Hart.*		
3-canaliculatus, *Hart.*		
4-canaliculatus, *Hart.*		
5-canaliculatus, *Hart.*		
	60.	60. Actinocamax verus, *Mill.*
ptychus lævis, *Meyer.*	61.	61.
imbricatus, *Meyer.*		
bullatus, *Meyer.*		
Elasma, *Meyer.*		
ychoteuthis angusta, *Munst.*	62.	62.
ligo prisca, *Rüppell.*	63.	63.
antiqua, *Munst.*		
pia hastæformis, *Rüppell.*	64.	64.

PART III.

THE METHOD OF ANALYZING MINERALS.

INTRODUCTION.

art of analyzing minerals, or of determining the different
edients of which they are composed, can scarcely be con-
ed to have originated before the middle of the last cen-
; for the chemical analysis of vegetables, undertaken by
ery, &c., and of mineral waters, by Dominic du Clos,
so imperfect and erroneous that they are hardly entitled
tention. Margraaff was the first chemist who attempted
etermine the true constituents of minerals by analysis;
48 he published his chemical experiments on the Osteo-
of the March of Brandenburg in the *Memoirs of the*
n Academy, and proved by satisfactory trials that the
ituents were carbonate of lime and silica, slightly tinged
iron. Bergman attempted not merely to analyze mine-
and mineral waters, but to reduce the method of proceed-
o a regular system. To him we are indebted for the first
nents of our present processes; in 1778 he was the author
n elaborate treatise on the analysis of water; he had pre-
sly published his analysis of the waters of Upsala and of
Denmark spring, of sea water, and on the artificial prepa-
n of mineral waters, both cold and hot. In the year 1777
ublished his experiments on the analysis of *gems*. He
ed that an earthenware crucible could not be employed
ch experiments, and substituted for a Hessian crucible a
el of polished iron. His method of proceeding was, to
ce the mineral to be analyzed to a very fine powder; this

powder was mixed with twice its weight of anhydrous carbonate of soda, and the mixture strongly heated for three o four hours in the iron vessel. The fused mass was taken out of the iron vessel and digested in muriatic acid till every thing soluble was taken up. The insoluble portion after ignition was examined by the blowpipe; if it fused with effervescence with carbonate of soda into a colourless glass it was considered as silica, if it did not effervesce nor fuse with the soda it was considered as a portion of the mineral undecomposed, which required to be again subjected to fusion with carbonate of soda in the iron crucible.

The muriatic solution was mixed with prussiate of potash, which threw down the iron, if any was present. The liquor thus freed from iron, was mixed with a sufficient quantity o fixed alkali, probably in the state of carbonate. The precipitate was washed, dried and ignited; it was then digested fo an hour in six times its weight of cold acetic acid. The aci dissolved any lime, barytes or magnesia that might be present while it left the alumina undissolved.

The acetic solution was thrown down by an alkaline carbonate. The precipitate was washed, dried, weighed and examined; if its neutral solution in muriatic acid was converted int sulphate of barytes, or into gypsum, or into epsom salt, whe mixed with a solution of sulphate of potash, the presence barytes, or lime, or magnesia was indicated. The undissolve portion was presumed to be alumina. This was determined b dissolving it in sulphuric acid and converting it into alum.

Such was the process of Bergman for the analysis of minerals—rude and imperfect undoubtedly, but exhibiting th rudiments of the methods at present adopted with so muc success by modern chemists. Klaproth, who began his chemical career almost at the termination of Bergman's usef life, took up the method of analyzing minerals where Bergma left it, and gradually corrected the imperfections of Bergman apparatus, and of his method of separating the different co stituents from each other. He substituted crucibles of pu silver for the iron vessels of Bergman. This was an impo tant step towards accuracy, because when iron vessels we used, it was scarcely possible to prevent some iron from t vessel from being mixed and confounded with the miner under examination. He substituted caustic potash in certai cases for the carbonate of soda used by Bergman, and showe that it was much more efficacious in such cases in renderin the mineral soluble in muriatic acid. He pointed out the necessity of obtaining a complete solution of the mineral under analysis in muriatic acid, and showed that when any insoluble portion remained it consisted almost always of the mineral undecomposed. He pointed out the necessity of evaporating the muriatic solution to dryness, and of digesting the dry residue in water acidulated with muriatic acid. What remained undissolved was silica, the purity of which was tested by fusing it before the blowpipe with carbonate of soda. To the muriatic solution thus freed from silica, he added an excess of caustic ammonia; the alumina, glucina, yttria, zirconia, oxide of iron and oxide of manganese were precipitated, but the barytes, strontian, lime, or magnesia remained in solution. The oxides of iron and manganese were separated from the earths by digestion in caustic potash; and Gehlen afterwards introduced the method of precipitating peroxide of iron and separating it from oxide of manganese by means of succinate of ammonia.

Klaproth's improvements in the art of analyzing metallic ores were no less important. Indeed, he in a great measure created this branch of the analytical art; almost all attempts at the analysis of such ores made before his time being unsuccessful.

About the year 1790 Vauquelin began his great analytical career, in Paris. His turn of mind led him to analytical investigations, which he prosecuted with much accuracy and with great delight. His skill as an analyser of minerals was little inferior to that of Klaproth, and his patience nearly as inexhaustible; but his analyses of minerals are much less valuable, not from any want of precision or of skill, but because sufficient care was not taken in selecting specimens for analysis. For it is too obvious to require illustration, that the chemical analysis of a mineral can lead to no useful results unless specimens of the greatest possible purity be selected. When Vauquelin was connected with the School of Mines, Haüy was engaged in his crystallographical researches, and had projected his *Treatise on Mineralogy*. At that time few analyses of minerals existed, and none to be depended on except those which had been made by Klaproth; this led him to request the assistance of Vauquelin, whom he supplied with specimens for analysis, and Vauquelin entered upon the task with great alacrity. The selection of the specimens then belonged to Haüy, and it must have been owing to the little care with which that illustrious crystallographer made his selection that so many of Vauquelin's analyses have been found inaccurate by more recent experimenters. To Vauquelin we are indebted for the first treatise on the analysis of stony bodies, in which the various improvements introduced into the processes by Klaproth and himself are fully detailed. This treatise was published in the year 1799,* and doubtless contributed very materially to the analytical skill which soon after became very general among practical chemists.

An improvement in the crucibles used for fusing the minerals subjected to analysis with carbonate of soda was still wanting to enable chemists to make their analyses with rigid accuracy. Silver crucibles, unless great care be employed in managing the heat, are apt to melt, and when this happens the analysis is of course destroyed. Silver is easily acted upon by the mineral acids. In nitric acid it dissolves as readily as sugar does in water, and both muriatic acid and sulphuric acid act upon it slowly, especially when the action is assisted by heat. This limits the use to which these crucibles can be put, and prevents the possibility of employing acids to remove from the silver vessel the last remains of the mineral mass which had been fused in it. The introduction of platinum crucibles by Dr. Wollaston, about the commencement of the present century, may be said to have carried the apparatus used in analyzing minerals to a state of perfection. It is only the analyses made since the introduction of these crucibles that can be depended on. Dr. Wollaston also made an important improvement in the art of analysis, by reducing the quantity operated on. Klaproth usually analyzed 100 grains of a mineral, and sometimes even 200 grains, and Vauquelin's quantity was not in general less; but Dr. Wollaston introduced the custom of taking a much smaller portion: 25 or even 20 grains was the quantity which he usually employed. This is attended with many advantages. It greatly shortens the time necessary for such analyses, and proudces a proportional diminution in the expense; even the accuracy of the result is rather promoted than injured, provided the requisite care be taken in all the steps, and the balance employed be nice enough to weigh to the hundredth of a grain with accuracy. If the mineral analyzed contain only substances with which the chemist is acquainted, he will find no difficulty

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* Ann. de Chim. xxx. 66.

determining their nature and weight, even when the quan- y does not exceed a grain or half a grain. If new substances, substances with the properties of which the chemist is not quainted, occur during the analysis, it may not be in his wer to determine them with accuracy. In such cases he ll naturally repeat his analysis upon a larger quantity of the ineral, that he may be enabled to produce the unknown bstance in sufficient abundance to determine its nature.

The art of analyzing minerals has now become so univer- lly known to chemists that it would be difficult to point out l the individuals to whom it lies under obligations. Stromeyer, rofessor of Chemistry at Göttingen, has devoted a great ortion of his time to the analyses of minerals, and has pub- shed a volume* containing no fewer than fifty analyses of inerals, made with the utmost attention to accuracy, and all f them models of analytical sagacity. He has pointed out arious improvements in the art of analysis, and his descrip- ions are so minute and exact, that the study of his work must e of very great importance to all who wish to acquire the ifficult but important art of chemical analysis. Thirteen years have elapsed since the appearance of this work, and Stromeyer has doubtless ample materials for another. That another volume has not hitherto appeared must be considered as injurious to the progress of analytical chemistry; probably the sale of such a work must be very limited, because it can interest nobody except practical chemists, the number of whom, unfortunately for the science, is but small. It is a pity that works of such importance to the progress of chemistry were not published at the expense of the State. Were the Göttin- gen, Berlin, Munich, &c. Academies in Germany enabled by their respective governments to publish works of sterling alue, but of limited sale, from the nature of the subjects, the ciences would advance with much greater rapidity than at resent.

Professor Berzelius of Stockholm must not be forgotten hen we are giving a sketch of the progress of analytical hemistry. He has been perhaps the most active chemist of is day, and has analyzed a greater number of minerals than ny other individual. His laborious investigations respecting

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* Untersuchungen über die Mischung der Mineralkörper. Erster Band. öttingen, 1821.

the atomic weights of bodies have contributed most materially to the precision of mineral analysis. Not satisfied with this he has contrived many new analytical methods, and as he has extended his researches to almost every kind of mineral, his analytical investigations are highly worthy of the study of all who wish to become adepts in this most important branch of practical chemistry. At one time of his life, Berzelius was in the habit of taking practical pupils, whom he instructed in the methods of analyzing minerals; and not a few of these pupils have since distinguished themselves as analysts. Of these, M H. Rose of Berlin has perhaps been the most active. H turned his attention to several complicated ores of copper an silver, remarkable for the number of their constituents, an has wonderfully disentangled one of the most complicate departments of mineralogy. His treatise on *Analytical Ch mistry*, in two volumes, the second edition of which appeare in 1831, is by far the most complete work on the subject, an is an indispensable book in the laboratory of every practic chemist. An excellent English translation of this book, b Mr. Griffin, was published some years ago, and its perus cannot be too strongly recommended to all those Britis chemists who wish to become adepts in mineral analysis.

Another of Berzelius's pupils, who has distinguished himse by numerous analyses both of minerals and salts, is Profess Mitscherlich of Berlin, though the high reputation which h has acquired is connected with other branches of the science chemistry, which cannot be alluded to here. Professor C. Gmelin of Tübingen is another pupil of Berzelius, who h in a great measure devoted himself to the analysis of minera His analyses are numerous and exact, and he has turned h attention to some tribes of minerals, the analysis of which attended with peculiar difficulty: the tourmalin may be me tioned as an example. For some years past we have se very little of his analyses in the German Journals. This ma probably be occasioned by the *System of Chemistry*, which is at present engaged in drawing up. Such a task, from t vast extent of the subject, is attended with considerab difficulty, and requires very extensive reading and research.

Professor Bonsdorff, formerly of Abo, is not the least di tinguished of the pupils of Berzelius. His analyses of t numerous varieties of Amphibole, published in the *Memo of the Stockholm Academy* for 1821, are perfect models chemical research. Nor is less praise due to many other important analyses which he has published, but which it would be impossible to particularize here.

In France by far the most active analyst of the present day is Berthier, who occupies the department formerly held by Vauquelin in the *School of Mines* in Paris. His memoirs, mineralogical, metallurgical, and geological, have been published chiefly in the *Annales de Chimie et de Physique*, and in the *Annales des Mines*. His analyses of minerals amount to more than a hundred, and he has lately published a most important work intimately connected with mineral analysis, entitled *Traité des Essais par la voie sèche*, in two very thick octavo volumes. It contains the result of many analytical investigations in this most important department of metallurgy, and must be a valuable addition to a branch of the science, which has been too much neglected by modern chemists.

If we except Mr. Hatchett and Mr. Chenevix, Great Britain has produced very few analytical chemists. Almost the only modern chemists of this country, who have published analyses of minerals, are Mr. R. Phillips, Dr. Turner, and Mr. Connell. The analyses published by these gentlemen are not numerous, but they are accurate, and characterized by a neatness and ingenuity which does them great credit. Mr. Connell's discovery of barytes and strontian in Brewsterite proves incontestibly the minute accuracy of his investigations, and augurs well for his future eminence in this branch of chemistry. The department of analytical chemistry, and even mineralogical investigations in general have been sneered at by several chemists in this country, as a branch of chemistry below the notice of men of true science. But such allegations are ill founded and improper. Mineralogy has been to chemistry what astronomy has been to mathematics—the cause of many improvements of the most important kind. If we turn our attention to the great improvers of chemistry, we shall find that they have been analytical chemists. Indeed the only means of advancing the science is analytical investigation, and the best school for acquiring the power of making such investigations is the study of the methods of analyzing minerals. A good analytical chemist must be familiar with the properties of the different substances which come under his investigation, and with the best methods of separating them from each other, and of determining their quantity. Among the chemists of the last century none acquired a higher or more deserved reputation than Scheele. Now all Scheele's discoveries were the results of analytical investigations. Cavendish's great discoveries of the constituents of water and nitric acid were the results of synthetical experiments, similar in their consequences to analytical investigations. Berthollet's discovery of the composition of ammonia was equally an analytical investigation, and the same remark applies to the great discoveries of Sir H. Davy, namely the constituents of the fixed alkalies and alkaline earths. For our knowledge of all the earths and most of the metals we are entirely indebted to those chemists who have devoted themselves to the analysis of minerals. In fact, had it not been for the new views that opened themselves in consequence of the chemical study of the mineral kingdom, the science of chemistry could have made but little progress.

Minerals, as far as analytical processes are concerned, may be divided into two classes. The first class consists of oxydized bodies, earths, oxides, and fixed alkalies, either combined with each other or with an acid. The second class consists of combustible bodies, namely, sulphur, selenium, metals, &c., united together. The methods employed in analyzing these two sets of bodies differing somewhat, it will be proper to consider each class separately.

BOOK I.

OF THE ANALYSIS OF OXYDIZED BODIES.

THE greater number of stony bodies, and even some metallic ores, belong to this class. Now the analysis of these bodies consists of three series of operations which must be conducted in succession. The object of the first is to know the quantity of water or other volatile matter which the mineral may contain. The object of the second is to ascertain the nature and number of the fixed constituents. While the object of the third is to determine the weight of each of these constituents.

CHAP. I.

METHOD OF DETERMINING THE QUANTITY OF WATER OR OF OTHER VOLATILE MATTER IN A MINERAL.

THIS is always the first step in the analysis of a mineral. Because, till the quantity of volatile matter be known, we have o data for estimating the accuracy of our analysis. Nor can e determine accurately the quantity of matter which we ust employ in order to ensure a correct result. The volatile atter is always lost during the process, and a deficiency in e weight would ensue, unless we knew its amount, which uld not be accounted for without supposing a mistake in e analysis.

Water may exist in minerals in two states. It may be emically combined with the other constituents, or it may only mechanically (so to speak) mixed with them. When mineral is porous, the pores almost always imbibe water by pillary attraction. But when a mineral is reduced to powr, the particles lying light upon each other, leave numerous erstices into which the air loaded with moisture makes its y. This moisture is deposited and retained by capillary attraction. Hence all powders contain water lodged betwee their particles even when no combined water exists in them

Many foliated minerals, as common salt, calcareous spa &c., when suddenly heated split with a crackling noise, whic is called *decrepitating.* This is a proof that such mineral contain water lodged mechanically between their plates. Th sudden heat by converting this water into steam, causes it tc expand and split the mineral in pieces, which occasions th decrepitation.

When water is chemically combined it always exists in mineral in a determinate quantity. Indeed when the quantit of combined water in a mineral changes, though the othe constituents remain unaltered, the properties of the miner alter, and it becomes a new species. Many examples of thi occur in the first part of this work, especially among magnesian, aluminous, and ferruginous minerals.

Some minerals contain carbonic acid, fluoric acid, muriat acid, or arsenious acid, all of which may be driven off by th application of heat, provided the bases with which they a combined do not retain them too powerfully. Thus carbon acid is easily driven off by a red heat when combined wi magnesia, oxide of zinc, oxide of lead, oxide of copper, oxi of silver, or oxide of bismuth. But it requires a white heat drive it off when combined with lime; and when it is unit to barytes or strontian, we cannot drive it off by heat witho some peculiar contrivance. Thus we separate it if we m the pounded carbonate with charcoal powder, and expose t mixture to heat; because the charcoal has the property decomposing the carbonic acid, and converting it into carbo oxide, which has no sensible affinity for barytes and stronti

Fluoric acid may be driven off from most minerals by he but a very high temperature is necessary for the purpo Hence, when a mineral contains water and fluoric acid, may sometimes determine the quantity of each. Incipi ignition will drive off the water, and its quantity may ascertained by weighing the mineral before and after igniti Afterwards a white heat will drive off the fluoric acid, and additional loss of weight will determine its quantity. T was the method employed by Bonsdorff, to determine quantity of fluoric acid in the different varieties of amphib which he analyzed.

When water only is present, as is the case with most mi rals, the process for detecting it is easy. Counterpoise

tinum crucible* in the scales of a delicate balance, and put
o it 20 grains of the mineral, either in crystals or in a
rse powder. Cover the crucible with its lid, and keep it
a quarter of an hour in a good red heat, either raised by a
rit lamp, or a charcoal or coal fire. When the crucible is
d enough to be handled, but not quite so cold as the air of
room, put it again into the scale of the balance, and
erve whether it is still counterpoised by the weights in the
osite scale. If not, add weights till the counterpoise is
ctly restored.† The weights thus added give you the
ntity of water driven off by the heat. Suppose 2 grains
equired to be added to the scale containing the crucible in
er to restore the equilibrium. This shows that the 20
ins of mineral had lost 2 grains by ignition, and conse-
ntly, that the water in the mineral amounts to ten per cent.
As powders have the property of imbibing moisture again
y speedily when exposed to the air, it is best to allow the
to remain on the crucible during the process of weighing.
e lid therefore should be weighed along with the crucible
first. It is best also to put the crucible into the scales
en about ten degrees hotter than the air of the room. You
not weigh with perfect accuracy, if the crucible be hotter
n the air; but so small a difference as ten degrees, which
liminishing during the process of weighing, will occasion a
ller error than is likely to arise from the imbibition of
ter, if the powder, when weighed, be cold and fully exposed
the air.

It is better not to reduce the mineral, whose water we
an to determine, to a fine powder, but only to fragments;
ause such fragments do not imbibe water so rapidly as a
e powder does.

When we suspect the presence of any volatile gaseous sub-
nce in the mineral, together with water, the process to be
owed is different.

It is convenient to have a brass counterpoise for the crucible; but the
erimenter ought to be aware that a platinum crucible loses weight by
. The crucible which I at present use in my analyses, is 11 grains
ter than when I first began to employ it.

† The weights used by chemists are grains. I use the following weights:

1000, 500, 400, 300, 200, 100 grains.
50, 40, 30, 20, 10 grains.
9, 8, 7, 6, 5, 4, 3, 2, 1 grains.
0·9, 0·8, 0·7, 0·6, 0·5, 0·4, 0·3, 0·2, 0·1 grain.
0·09, 0·08, 0·07, 0·06, 0·05, 0·04, 0·03, 0·02, 0·01 grain.

Weigh a small bottle glass retort, and mark on it the weight with a diamond. Introduce into it 100 grains of the mineral under examination, previously reduced to a fine powder. To the beak of this retort, a glass tube about a foot long, and filled with fragments of chloride of calcium that have been fused, is to be luted. The fragments of chloride of calcium, are to be of such a size as to leave a free passage to air, while at the same time, they fill up the whole of the tube, which ought to have a diameter of about $\frac{5}{8}$ths or $\frac{1}{2}$ of an inch. At the two extremities of the tube, a little amianthus or cotton, must be introduced, to keep the chloride of calcium from passing into the retort or falling out of the tube. The glass tube is fitted to the retort (so as to be air tight) by a perforated cork introduced into the end of the tube, through which the beak of the retort passes. To insure accuracy, the retort and tube ought to be luted together by a ribbon of caoutchouc tied firmly to the tube and retort by a string.* The tube with its chloride of calcium, must be accurately weighed before it is luted to the receiver.

The belly of the retort is placed upon a chauffer containing a charcoal fire. It must be cautiously heated at first to prevent it from cracking. By degrees the heat is raised till the powder become distinctly red hot, and it must be kept red hot for at least an hour, and then the whole is to be left to cool. The retort and glass tube are then to be separated, cleaned and weighed. The loss of weight sustained by the retort gives the water and elastic fluid evolved by the heat from the mineral. The increase of weight of the glass tube gives the quantity of water, and this weight subtracted from the loss sustained by the retort, gives the quantity of elastic fluid evolved. Suppose the retort to have lost 20 grains, and the glass tube to have gained 15 grains, the inference would be, that the mineral had given off 15 grains of water and grains of elastic fluid.

If the process has not been continued long enough, or the quantity of elastic fluid evolved be very small, we observe a little water in the beak of the retort. This may be removed by means of a slip of bibulous paper applied to the place whe

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* The best caoutchouc for the purpose, is what is sold in London in thin sheets. I besmear one side of such a ribbon with a varnish composed caoutchouc dissolved in naphtha, wrap it tight round the place where the tube and retort beak come in contact, and then tie it firmly with a piece twine.

the water is lodged, taking care to determine its amount by weighing the retort before and after it is dried. Should drops of water appear attached to the beak of the retort, too high up to be removed by bibulous paper, we must proceed in the following manner:—The retort is first weighed. It is then placed again on the charcoal fire, and heated till every part, beak and all, is hotter than boiling water. We now push as far into the retort as possible, a small glass tube open at both ends, and quite dry. By drawing air from this tube with the mouth, we cause a current of air to pass through the hot retort, which in a few minutes renders the inside of it quite dry. The retort being now weighed again, the loss of weight sustained indicates the quantity of water which has been driven off by this drying process.

The water driven off from minerals by heat, may be collected also in a small receiver attached to the beak of the retort by lute. But the simplest way of examining this water, is to put a quantity of the mineral into a thin glass tube shut at one end. The portion of mineral at the bottom of the tube is gradually heated, almost to redness, over a spirit lamp, while the tube is held in nearly a horizontal position. The water is driven off by the heat, and is condensed in the cold part of the tube. In this situation it may be easily examined by re-agents, and its purity determined.

Some minerals, as mica, pyroxene, &c., when treated in this way, give a few drops of acidulous water. The sour taste is owing to the presence of a little fluoric acid; the presence of which may be known by the following properties:—

(1.) When a drop of the liquid is evaporated to dryness on a slip of glass, a particle of silica remains on the glass, easily known by its white colour and insolubility in acids.

(2.) It gives a yellow colour to paper stained with brazil wood.

In some cases the acid is the fluoboric. This acid does not corrode glass. It renders brazil wood paper yellow; but when the paper is dried, it becomes white in the place where the acid liquid had been applied.

It is scarcely necessary to observe, that if any other substance, besides water, be distilled over, it must be examined by the rules about to be given.

Porcelain retorts may be used instead of green glass ones. Indeed, when the mineral requires to be exposed to a white heat, as is the case when our object is to drive off the fluoric acid, no other retorts but those of porcelain can be employed. The best porcelain retorts are those of Berlin.* They bear sudden changes of temperature without cracking, much better than those made in this country. The small Wedgwood retorts occasionally employed in this country are very bad. They seldom stand two processes, and often crack the first time we attempt to heat them.

When we have ascertained that a mineral when exposed to a red heat, besides water, gives out some other gaseous substance, the next point is to determine the nature of the gaseous body evolved. For this purpose a bent tube is to be luted to the extremity of the tube containing the chloride of calcium, and by means of it the gas is to be conducted to a glass jar standing over a water, or mercurial trough. If it render lime water or barytes water milky, it is carbonic acid. If it occasion a curdy precipitate when passed through a solution of nitrate of silver, it is chlorine. If it produces no sensible effect with these re-agents, but causes a stick of phosphorus when immersed in it to smoke, while the gas gradually disappears, it is oxygen gas. Scarcely any other gas except these three, is evolved when minerals are exposed to a red heat. Should any others make their appearance, the mode of determining their nature will be given afterwards.

CHAP. II.

METHOD OF DETERMINING THE NATURE OF THE FIXED CONSTITUENTS OF MINERALS WHICH ARE BASES.

It is needless to attempt a rigid analysis of a mineral till we know the substances of which it is composed. Because the plan of analysis cannot be devised or arranged till we are aware what the bodies are which must be separated from each other. This second step of the analysis then is an essential one, and ought never to be neglected.

1. Before we can detect the constituents of a mineral, we must have it in a state of solution. Some of the minerals (most of the *zeolites*, for instance) may be dissolved at once

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* Dresden porcelain is said to be equally good, but I have never tried it. Sèvre porcelain, from Paris, is apt to crack in the glazing.

in an acid; but the greater number are not acted on by acids till they have been heated with a fixed alkali.

When a mineral is directly soluble in acids, we may employ ither nitric or muriatic acid as the solvent. But muriatic cid is preferable, except in certain cases, which will easily ggest themselves to an analyst acquainted with the properes of the constituents of mineral bodies. It is needless to serve, that the acid employed should be pure. Were it ntaminated with sulphuric acid, for example, it would not solve the mineral completely if it contained lime, strontian, barytes.

The first step of the process is to reduce the mineral, under amination, to powder. This is a most important part of process; the success of an analysis sometimes depending on the reduction of a mineral to a very fine powder. This s well exemplified, in my laboratory, a good many years o :—I gave to two of my practical pupils, a quantity of rysoberyl from Brazil, to analyze. One of the gentlemen as at great pains in pounding it, and reduced it to the finest ossible powder. He fused it with thrice its weight of anhyrous carbonate of soda, and kept it in that state for a couple of ours. It was thus rendered soluble in muriatic acid, and the nalysis was happily conducted and finished in a few days. he other gentleman was not at the same pains in pounding is portion of the mineral. After fusing it successively with arbonate of soda, and then with caustic potash, and spending great many days in these disagreeable repetitions, he was nable to render the mineral soluble in muriatic acid, and ave up the analysis in despair. On examining the powder n which he had been operating, I showed him that it had not een made fine enough, and satisfied him by a repetition of e process, that want of care in pounding was the only reaon of his failure.

The mineral to be pounded (if it happens to be in a mass, is usually the case) must, in the first place, be broken into all fragments. This is easily accomplished by means of a mmer and anvil, which ought therefore to be kept in every boratory where minerals are analyzed.

The fragments thus obtained, are to be introduced one by e into the steel mortar employed for pounding diamonds, d therefore called a *diamond mortar*, and by repeated blows the hammer, reduced to a moderately fine powder. The mond mortar consists of a cylindrical vessel of polished steel, about 2 inches in diameter, and $1\frac{1}{2}$ inch in depth. Into this cylinder, another cylinder or ring of steel is fitted. It goes to the bottom of the first cylinder, and is fixed in its place by two pieces of iron which pass through two holes in the outer cylinder, and penetrate so far into this internal cylinder or ring. This cylinder is about an inch and a half in depth, and has a circular hole in the centre about $\frac{3}{4}$ inch in diameter, and open both above and below. A pestle of steel is ground to fit this cylinder. The fragments of the mineral to be pounded are introduced into the cylinder one by one, the pestle is put into its place, the mortar is laid on the anvil, an by repeated strokes of the hammer, the fragment is reduce to powder.

A little of this powder (not more than two or three grai at a time) is put into a small chalcedony mortar, and pounde by means of a chalcedony pestle till it feels quite smooth unde the pestle, and till it begins to cohere together. A littl perseverance and address will enable us by this process alon to bring the mineral to a powder sufficiently fine. But if w are afraid that some particles may have escaped the action o the pestle, when the stone is very hard and difficult to poun the best way is to pound the whole a second time, adding little distilled water, and rubbing it upon the chalcedony morta till the whole is reduced to the consistence of cream. Thi cream is to be washed into a glass jar, and stirred up wit water. After allowing it to stand a few seconds, that th larger particles may fall to the bottom, the milky liquid poured off, and the coarser particles are ground anew, mixe again with water, the milky liquid again poured off, and thes processes of grinding and floating are continued till the whol is reduced to so impalpable a powder that it has been all floate off without leaving any residue whatever.

This fine impalpable powder is allowed to subside, the wat is drawn off, and the powder dried, first on the sand bath, an afterwards by exposure to a red heat in a platinum crucible.

It is scarcely possible to grind a mineral in this mann without loss, and in some cases it is essential to know precise the amount of this loss, because when the mineral is very ha (as sapphire, corundum, chrysoberyl,) a portion of the chalc dony mortar is ground down along with it. Before beginni to pound such a mineral, the chalcedony mortar must weighed, and its weight noted down. Weigh it again aft the process is finished: the difference between the two weigh ves you the quantity of matter which has been abraded from e mortar.

In like manner the mineral is to be weighed before we begin pound it, and the pounded mineral is to be weighed after ving been exposed to a red heat. The knowledge of these rticulars will enable us to determine the quantity of silica raded from the mortar which is contained in the powder to subjected to analysis.

Let the loss of the mortar, . = 4 grains.
weight of unpounded mineral, = 20
weight of powder collected, = 22

discover the quantity of silica from the mortar contained these 22 grains, we say, 24 : 4 : : 22 : $3\frac{2}{3}$ = quantity of ca from the mortar contained in the 22 grains of powder. nce that powder is composed of

Pure mineral, .	$18\frac{1}{3}$
Silica from mortar, .	$3\frac{2}{3}$

e general formula is as follows :—

Let weight of mineral, . . $= a$
loss of mortar, . . . $= b$
weight of powder, . . $= c$

ica abraded from the mortar, contained in the powder, $= x$.

en
$$x = \frac{bc}{a + b}.$$

It is needless to observe that when the mineral is analyzed, s portion of silica must be carefully subtracted.

The powder should be weighed before the crucible is quite d. It is best to weigh it in the crucible in which it is to afterwards fused, because it is scarcely possible to transfer ery fine powder from one vessel to another without loss.

When the mineral under analysis is soluble in acids, we interpoise a clean glass flask, and then introduce into it, ile still in the scales, the quantity of powder which we an to examine ; or we may weigh the powder in a watch ss, and after introducing as much of it as we can into the sk, wash in the remainder by letting fall into the watch ss, while held inclined over the mouth of the flask, a small eam of distilled water from the extremity of a sucker. If s method be carefully executed, it occasions no loss whater. Muriatic acid is now poured into the flask in sufficient antity to dissolve the powder. In general it is better to ute the acid with twice its bulk of water; though there are me cases, to be noticed afterwards, when the acid is required to be as concentrated as possible. The flask being placed on the sand bath, is allowed to remain till the whole powder is dissolved. We ought to watch the moment when the solution is complete, because soon after this the silica (if it be a constituent of our mineral) assumes the form of a jelly, and if this be allowed to remain a little while in the vessel it adheres so firmly to the bottom of the flask that it cannot be washed out.

When from an oversight of this nature the silica, or a portion of it, adheres to the inside of the flask, we must not attempt to remove it by drawing a glass rod over the adhering portion. This would not remove the whole of the silica, but it would almost always be sure to destroy the flask, by driving out its bottom. The best way is to pour some dilute potash or soda ley into the flask, and place it again on the sand bath. In a few minutes the whole adhering silica will be dissolved, while the flask, if the ley be dilute, will not be attacked. This ley being poured out is to be saturated with muriatic acid, and evaporated to dryness in a porcelain vessel. Water will dissolve off the chloride of potassium or sodium and leave the silica, which may be washed, dried, and ignited.

Some minerals dissolve easily in acids before ignition, but lose their solubility after being deprived of their water by exposure to a red heat. Many of the zeolites are in this predicament; they are hydrous silicates of alumina, lime, soda, &c. In such cases one portion of the mineral must be employed to determine the quantity of water which it contains, and another for solution in acids.

Minerals soluble in acids are in general soft and easily pounded. They never abrade the chalcedony mortar.

When a mineral is insoluble in acids, we in general give it solubility by mixing it with twice or thrice its weight of anhydrous carbonate of soda, and keep the mixture in a state of ignition for about an hour in a platinum crucible. The mineral and the carbonate are first intimately mixed together by rubbing them together in a mortar. Should any thing adhere to the mortar it may be removed by triturating in it a new quantity of carbonate of soda, which is to be added to the mixture. In some cases the mineral requires more than twice its weight of carbonate of soda to render it soluble; in some rare cases as much as six times its weight of that alkaline carbonate is requisite.

The crucible, covered with its lid, is exposed at first to a gentle heat, which is gradually increased to ignition, and it is kept in a red heat for about an hour. Towards the end of the process it is good to raise the heat sufficiently to produce fusion. If we raise the temperature at once high enough to produce fusion, the carbonic acid, if the mineral contain much silica, is driven off so rapidly that portions of the melted matter are dashed about, and may be lost by running out between the crucible and the lid. It is not necessary to raise the temperature so high as to produce fusion, though I generally do so. The whole process may be conducted over a spirit lamp, but in general it is more convenient to make use of the fire which is kindled for heating the sand bath.

Some minerals cannot be decomposed or rendered soluble by heating them with carbonate of soda, but require to be ignited with caustic potash, or soda. This is the case with minerals containing zirconia, oxide of tin, and perhaps also columbic acid. Though I find that I can make minerals containing this acid soluble by fusing them with a sufficient quantity of carbonate of soda.* When a caustic alkali is employed, we must employ a crucible of pure silver, because the caustic alkalies act upon platinum. The mineral (previously reduced to a very fine powder) is weighed in the crucible, and then mixed with from four to six times its weight of the alkaline hydrate. The application of the heat requires very great care, because the hydrate of potash melts easily, and the escape of its water during the process occasions a boiling and agitation by which portions of the mixture are apt to be driven out and lost. The crucible should be deep and covered with a lid. The heating is best performed over a spirit lamp, which may have a circular wick, and a short copper chimney. This gives a sufficient heat, and it can be conveniently applied. Too high a temperature would fuse the crucible. When the water has been driven off, the mixture in general loses its fluidity. The crucible should then be raised to a red heat and kept in that state for an hour.

When the process is concluded, and the crucible allowed to cool, the next step is to dissolve the whole matter contained in it in dilute muriatic acid. When carbonate of soda has been employed, and the heat never so high as to fuse the mixture, if we invert the crucible over a porcelain dish, and give it a few gentle blows with a hammer, the mixture is

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* I have succeeded also with the zircon when sufficient care is taken to reduce it to the finest possible powder.

loosened and readily drops out. But when fusion has taken place, the matter adheres so firmly to the crucible that we can seldom disengage it in that way. We must in such a case pour the dilute muriatic acid into the crucible till it fill about two-thirds of it, and place the crucible on the sand bath covered with a slip of glass till it ceases to effervesce. The liquid is then poured into a porcelain basin, taking care to scrape the surface of the undissolved portion with a platinum spatula. More dilute muriatic acid is poured into the crucible, and the same steps repeated till a complete solution is effected.

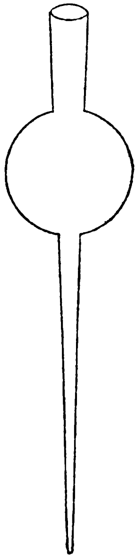
If we employ muriatic acid sufficiently dilute, and if the mineral has been sufficiently acted on by the carbonate of soda, a complete solution is obtained, or only a few white flocks remain undissolved, easily distinguishable from undecomposed mineral. If any portion of the mineral has escaped the action of the alkaline carbonate, it will be seen at the bottom of the basin in the form of a dense heavy powder. If the muriatic acid be too strong, the silica instead of dissolving is separated in white flocks.

The porcelain basin is now placed on the sand bath, and the liquid in it slowly evaporated to dryness. To prevent any dust from falling into it while the evaporation is going on, lay two glass rods, or two platinum wires across the mouth of the basin, and cover its surface with a piece of wrapping paper. When the liquid has become concentrated, if the mineral contains a considerable portion of silica, the silica assumes the form of a jelly, transparent and tremulous, and often tinged yellow with iron, which is a very general constituent of minerals. When this jelly has become a little stiff it should be scraped off the bottom with a platinum spatula, and very frequently stirred till it is converted into a dry powder. It is best to continue the heat till the powder ceases to give out muriatic acid fumes. For unless this be done a portion of the silica is apt to retain water, which causes it to dissolve partially again when water is poured on the powder.

When the powder is dried in this way, the oxide of iron, alumina, and even the magnesia, should such bodies be present, have generally lost a portion of their acid, and have in consequence become partially insoluble in water. To restore their solubility the dry mass is to be moistened with concentrated muriatic acid, and the mouth of the vessel being

vered with a glass plate, it is left for one or two hours on
e sand bath exposed to a gentle heat. Water is then to be
ured into it, and after a little digestion the whole is to be
rown on a filter. The dissolved portion passes through,
it the silica, which is in the state of a fine white powder,
mains on the filter. It must be washed with boiling hot
stilled water till the filtered liquid ceases to be affected
nitrate of silver; a salt which causes a white flocky pre-
itate to appear as long as any muriatic acid is contained
the water which passes through.

The washing of a filter requires some precautions, other-
se the upper part of the paper is apt to retain a portion of
solution after the under part is washed.
is is prevented by employing the glass
e represented in the margin, which,
m the mode of using it, may be called
ucker. It is about fifteen inches long,
l the upper extremity has an internal
meter of about half an inch, but at the
er end it narrows so as to be almost
not quite capillary. About two inches
n the upper end the tube is blown by
lamp into a spherical cavity capable
holding about a cubic inch of water.
e narrow end of the sucker is dipt into
hot water, and by the mouth which is
lied to the other end, the water is
wn into the tube till the spherical cavity
illed. We then place the sucker in
h a direction that the jet of water forced
of it with some violence by the action
the cheeks strikes against the upper edge of the filter, and
gradually turn the filter round so that the water may
ike against every part of the upper edge. This process
continued without intermission till the upper edge of the
er is quite tasteless, and till the water which passes through
filter is not precipitated by nitrate of silver. A good deal
washing, and for a considerable time is requisite before
se objects are accomplished. But they are indispensable
we wish to obtain accurate results.



When the mineral had been fused with caustic potash in a
er crucible, and the fused mass dissolved out with muriatic
d, the silica is always mixed with some chloride of silver.

This chloride may be removed by digesting the silica in caustic ammonia; but it is better to avoid the formation of chloride of silver altogether. This may be done by dissolving the matter out of the crucible by distilled water, and not adding the muriatic acid till we have got the whole into a porcelain basin.

While the muriatic solution is evaporating care should b taken not to allow it to boil, because whatever is driven upo the paper cover is lost. When the liquid has become so concen trated that strong muriatic acid fumes are exhaled, we shoul remove the paper cover altogether, because if allowed to remai it would be corroded and would at last fall into the acid liqui This would not only be troublesome from the quantity paper flocks mixed with the constituents of the mineral, b it would render the results inaccurate, because the earthy co stituents of the paper thus corroded would be confound with those of the mineral.

The silica thus separated, to be pure, must possess the fo lowing characters:

(1.) It is a fine white powder and continues white aft ignition. It feels gritty between the teeth.

(2.) When digested in muriatic acid after having be exposed to a red heat it is altogether insoluble.

(3.) After ignition it is tasteless and quite insoluble water.

(4.) When heated before the blowpipe with its own weig of anhydrous carbonate of soda it fuses, with a strong effe vescence, into a transparent colourless glass. This is t usual test by which pure silica is recognised by chemists.

(5.) When silica has been dried, but not exposed to a r heat, it dissolves completely when digested in a ley of caus potash or soda. The solution is colourless and does not gel tinize however concentrated.*

(6.) If we mix it after ignition with 3·375 times its weig of anhydrous carbonate of soda, and expose the mixture in platinum crucible to a strong red heat, it fuses into a colo less glass, which, when pounded and digested, dissolves water without leaving any residue.†

(7.) Dried (but not ignited) silica dissolves readily by t

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* Even after ignition silica dissolves in alkaline leys, but the process slow.

† If the silica contain any lime, barytes, strontian, or magnesia, the gl formed is not completely soluble in water.

assistance of heat in solutions of carbonate of potash or soda; but on cooling the solution assumes the form of an opal-coloured jelly, which is the stiffer, and forms the more rapidly, the more concentrated the solution is. This solution succeeds also when ignited silica is used, but it is much slower and more imperfect.

(8.) Fluoric is the only acid which dissolves silica after it has been dried in a red heat. The solution takes place rapidly, and the more so the more concentrated the fluoric acid is; when it is so strong as to smoke when exposed to the air, the solution of the silica sets so much heat at liberty that the whole acid is raised to the boiling temperature. These experiments must be made in vessels of silver or platinum, because fluoric acid instantly corrodes glass.

(9.) When a soluble combination of silica and an alkali is dissolved in a great deal of water, if we pour muriatic acid, or, indeed, any other acid, into the liquid, the silica is not precipitated, but remains in solution. If we now evaporate this liquid till it has reached a certain point of concentration, and then allow it to cool, the silica assumes the form of a white jelly, exceedingly similar to a jelly of isinglass. If we pour water upon this jelly, the greater part of the silica separates in white flocks, but a portion dissolves again. This is the reason why it is necessary to bring the muriatic acid solution of a mineral containing silica to the state of a dry powder before we attempt to separate the silica.

All deviations from these properties indicate the presence of a foreign body in the silica. It is necessary in such cases* to treat the silica again with an alkaline carbonate, as we did with the mineral at first; we must then get a solution of the whole in muriatic acid, and proceed as before, till we separate the foreign body from the silica.

II. The filtered liquid thus freed from silica contains the remaining constituents of the mineral in solution, combined with muriatic acid and mixed with abundance of common salt. There is also an excess of muriatic acid present. This liquid, together with the water employed in washing the silica, is to be put into a porcelain basin and evaporated on the sand bath till its volume is reduced to about ten cubic inches.†

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* For example, when it fuses into a coloured glass with carbonate of soda.

† To economise time, which is an object in chemical analyses, I usually reserve the last washings of the silica, containing very little impurity. The

The excess of muriatic acid is then to be nearly saturated by pouring into it carbonate of ammonia, taking care to agitate the liquor strongly and for some time, in order to get rid of the carbonic acid; and to make sure of this a little excess of muriatic acid ought to be allowed to remain in the liquid. To make sure of the escape of all the carbonic acid, it is best to heat the liquid almost to the boiling temperature and then allow it to cool.

This done we pour into it caustic ammonia, till the liquid, after agitation, smells sensibly of that alkali. Unless we add ammonia in excess, the precipitate which falls is apt to contain muriatic acid, and is in part redissolved again while we are washing it on the filter. But we should avoid a great excess of ammonia, because it might dissolve a portion of some of the substances at first precipitated.

The ammonia throws down every base which the solution can contain, except the fixed alkalies, barytes, strontian, lime and magnesia. If the solution contained protoxide of manganese, a portion of it will remain in solution, and the more the greater the proportion of sal ammoniac which our liquid contains. Magnesia will be partially precipitated by the ammonia, unless the solution contains enough of sal ammoniac to convert the whole magnesia into a double salt. If iron be present in the solution, and if we have not converted it into peroxide, a portion of protoxide of iron will also remain in solution.

Should oxides of zinc, nickel, cobalt or copper, be present, the greater part of these oxides would remain in solution. But these bodies are rare ingredients, except in ores: we shall therefore defer giving an account of the mode of detecting them till we come to the second book of this treatise.

III. The ammonia precipitates certain earths and metallic oxides. We leave the whole in a cylindrical glass jar, the mouth of which is covered with a plate so as to exclude the external air till the precipitate subsides, which it does slowly. The clear liquor above the precipitate is now carefully drawn off, by means of a sucker, and preserved. The precipitate, thus freed from a considerable portion of the liquid, is mixed with distilled water and thrown upon a filter: it must then be washed with boiling hot distilled water till every thing

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muriatic liquor is evaporated almost, but not quite, to dryness, and then mixed with these washings. This serves two purposes; it saves time and it gets rid of a good deal of the excess of muriatic acid present.

soluble is removed. This process is tedious, especially when the precipitate contains much alumina, because alumina forms a plastic jelly-looking mass, through which water filters but slowly.

IV. The liquid which passes through the filter may contain any or all of the alkaline earths. It may also contain portions of any of the metallic oxides that are soluble in ammonia; namely, oxides of zinc, manganese, nickel, cobalt and copper. Oxides of zinc and manganese do not communicate any colour to the liquid; oxide of copper gives it a blue colour, with a shade of red, oxide of nickel communicates a pure sky-blue, and oxide of cobalt a reddish-brown colour.

The first thing to be done with this liquid is to mix with it a few drops of sulpho-hydrate of ammonia; if a precipitate all, it indicates the presence of one or more of these metallic oxides. Let this precipitate be collected, washed and dried, upon a slip of glass or a piece of platinum foil. It consists of one or more metallic sulphurets.

(1.) Sulphuret of cobalt and nickel have a greyish-yellow or yellowish-grey colour, and when heated acquire something of the metallic lustre. Sulphuret of manganese, while still moist, is yellowish, but when heated it becomes green; sulphuret of zinc,* while moist, is white, but when heated it acquires a yellowish colour.

(2.) The easiest way of determining the nature of the metal in these precipitates is to test them before the blowpipe. The following instructions will enable the young analyst to accomplish this object.

The first step is to roast the sulphuret on charcoal, by the autious application of the blast, taking care not to fuse it, hich would prevent the object in view. This roasting must e continued till the whole of the sulphur is driven off, and he metal reduced to an oxide.

Sulphuret of zinc does not fuse, but it forms an annular eposit of the oxide of zinc, when strongly heated in the exrior flame on charcoal. When heated with carbonate of oda the zinc is reduced, and in a good flame burns, and flowers f zinc are deposited on the charcoal.

Sulphuret of manganese, when properly roasted on charcoal, s converted into brownish scoriæ, constituting an oxide of manganese. When this oxide is fused with carbonate of soda

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* It is, in fact, a sulpho-hydrate of zinc.

before the blowpipe, a green transparent bead is obtained, which on cooling becomes bluish-green and opaque. This experiment is best made on platinum foil. A very minute quantity of manganese may be detected by this colour. With borax it fuses into an amethyst-coloured glass, which loses its colour in the reducing flame; but if we add a little nitre and fuse again, the amethyst colour is restored with considerable intensity. If the quantity of manganese be considerable, compared with the borax, the glass in the exterior flame becomes so deep coloured as to appear black. With biphosphate of soda it fuses into a transparent colourless glass in the reducing flame, and an amethyst-red in the oxidizing flame; but never so deep as to render the glass opaque.

Sulphuret of copper, after the sulphur has been driven off, melts with carbonate of soda into a fine green glass, which loses its colour and transparency on cooling. With borax in the oxidizing flame it fuses into a fine green glass, which becomes colourless in the reducing flame; with biphosphate of soda it fuses and exhibits the same phenomena as with borax. If the quantity of copper be so small that the blue colour cannot be developed in the reducing flame, add a little tin to the assay and continue the blast. The bead now becomes red and opaque on cooling. If the blast be kept up too long, the copper precipitates in the metallic state, and the colour is destroyed.

Sulphuret of cobalt, after being roasted, fuses readily with borax or biphosphate of soda into a transparent blue bead.

Sulphuret of nickel, after being roasted on charcoal, readily fuses with borax or biphosphate of soda into an orange-yellow or reddish glass, which becomes yellow or almost colourless by cooling. If the proportion of oxide of nickel be great the glass is opaque and dull brown while in fusion, but on cooling becomes dull red and transparent. It behaves in the same way in the oxidizing and reducing flames; this distinguishes nickel from iron, which, in the colours that it communicates, it much resembles.

After determining the kind of metallic oxides, if any be present, in the solution, we next test it for lime, barytes, strontian, and magnesia.

1. The presence of lime is indicated by the white precipitate produced when the liquid is mixed with oxalate of ammonia. To apply this test put a little of the ammoniacal liquid into a watch glass, and let fall into it a drop of the aqueous solution of oxalate of ammonia. The presence of

e in the liquid will be immediately indicated by a white cipitate appearing in it.

hould the presence of oxide of manganese have been cated by the application of sulphohydrate of ammonia, and consequent examination of the precipitate, it is possible the white precipitate produced by the mixture of oxalate mmonia may consist of oxalate of manganese instead of ate of lime. To decide the matter, we must collect, wash, dry a little of the precipitate, and then heat it to redness piece of platinum foil. If it consisted of oxalate of lime, ill become grey, and will dissolve with effervescence in iatic acid, except a few flocks of charcoal. If it consisted xalate of manganese, it will become black after ignition, will dissolve in muriatic acid, giving out a strong smell hlorine. The solution will be colourless, and will be ipitated yellow by sulphohydrate of ammonia, whereas solution of the lime in the same acid will not be precipid at all by sulphohydrate of ammonia.

n applying the test of oxalate of ammonia to detect the ence of lime, the liquid should be dilute. If too much centrated, barytes and strontian might be thrown down as l as lime.

. Sulphate of soda in solution, when added to the liquid, cts the presence of barytes and strontian by throwing n a white precipitate. The liquid is to be tested for e two bodies in the same way as for lime. To determine ther the precipitate be sulphate of barytes or sulphate of ntian, we saturate a few drops of the ammoniacal liquid muriatic acid, and then let fall into it a drop of fluosilicic . A precipitate will appear if it contain barytes, but not contain only strontian.

. Should none of these three alkaline earths be present, we t next test the ammoniacal liquid for magnesia. This is e by saturating a few drops of it with phosphoric acid, or ping into it a little biphosphate of ammonia. If magnesia be ent a white precipitate falls, or at least lines drawn on the ch glass containing the liquor will become visible in a few utes by the precipitation of a little ammonia-phosphate of gnesia. Should our liquid contain lime, we must precipi the whole of that earth from it and filter the solution ore we test it for magnesia. Because phosphoric acid and hosphate of ammonia have the property of throwing down e from its solution in acids.

V. Having thus ascertained the nature of the substances which remain in solution, we must next turn our attention to the precipitate which was thrown down by ammonia, and which had been carefully washed on a filter. We dry it upon this filter without exposing it to heat.

The precipitate thus obtained is put into a flask with a sufficient quantity of moderately strong potash or soda ley, and boiled on the sand-bath for an hour, or for several hours, if the quantity be considerable. The potash will dissolve the alumina and glucina should these earthy bodies be present, while it leaves the other constituents undissolved.

When the boiling has been continued till every thing soluble has been taken up, we allow it to cool, and throw the whole on a filter to separate the dissolved from the undissolved portion. The filter is to be washed with the same precautions as before indicated, till every thing soluble is carried off.

The alkaline liquid, together with the washings, being reduced to a quantity sufficiently small for convenient examination, is saturated with muriatic acid, added in such excess, as to dissolve the whole of the precipitate which at first appeared. Then add a sufficient quantity of carbonate of ammonia to throw down the whole earthy matter held in solution, and put the mixture into a glass phial with a ground stopper. Let it remain at rest till the precipitate has subsided, and draw off the clear liquid by means of a sucker. Pour over the white precipitate a considerable quantity of a moderately strong solution of carbonate of ammonia, replace the ground stopper, and agitate the whole pretty strongly at intervals for several hours. Then allow the undissolved portion to subside. Draw off the clear liquid, and pouring in an additional portion of carbonate of ammonia, repeat the agitation as before. The carbonate of ammonia will dissolve the glucina, should any be present; but it will leave the alumina in the state of white, light, and very fine flocks.

The undissolved alumina is separated from the ammoniacal solution by means of a filter, which is to be washed with the precautions already described.

Boil the ammoniacal liquid in a flask, till the greatest part of the ammonia is expelled. It becomes milky, and deposits the glucina under the form of a bulky white powder.

If the carbonate of ammonia be employed in very great excess, it dissolves not only the glucina, but a portion also of the

mina. This portion renders the liquid muddy as soon as
egins to boil. It might be separated by stopping the pro-
s, and allowing the alumina to subside before we separate
glucina.* The precipitate thus obtained, is a mixture of
mina and glucina. Add a little carbonate of ammonia, and
it aside for a few hours to digest. The glucina will be
olved, and will leave the alumina unaltered.

lucina, when separated, washed, and dried, is a soft white
der, without taste or smell. It is insoluble in water, but
olves readily in acids, provided it has not been exposed to
d heat. Its acid solutions are colourless, and are distin-
shed by a sweet taste.

lucina is precipitated from its solution in acids, by a solu-
of potash, in a voluminous precipitate, which dissolves
pletely in an excess of potash. If this experiment be
le with a solution of sulphate of glucina, the solution,
ugh set aside, deposits no crystals of alum. This circum-
ice readily distinguishes glucina from alumina.

mmonia produces equally a voluminous white precipitate
en poured into solutions of glucina, and the precipitate is
re-dissolved by an excess of ammonia; nor is it prevented
n falling, though a quantity of sal ammoniac be mixed with
solution.

solution of carbonate of ammonia likewise produces a
ky precipitate in solutions of glucina, which is re-dissolved
an excess of the carbonate. This also distinguishes glu-
from alumina.

arbonate or bicarbonate of potash acts in the same man-
; only it requires a greater excess of these bodies than of
carbonate of ammonia to re-dissolve the precipitated glu-
a.

Alumina, when pure, is a soft, white, tasteless, powder,
ring externally considerable resemblance to glucina. It
insoluble in water, but dissolves readily in acids, provided
as not been ignited. After ignition, it dissolves slowly in
riatic or sulphuric acid by digestion on the sand-bath. The
d solutions of alumina have a sweet and astringent taste.

Like glucina, alumina is precipitated from its solutions by
stic potash, and the precipitate is again re-dissolved by
ing the potash in excess. It is also precipitated by am-
nia, but no excess of this alkali re-dissolves it. It is pre-

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* The quantity is so small that this process is unnecessary.

cipitated equally by carbonate of potash, bicarbonate of potash, and carbonate of ammonia; but no excess of these carbonates is capable of re-dissolving the precipitate.

When to a solution of alumina in sulphuric acid we add sulphate of potash, or sulphate of ammonia, and set the solution aside, crystals of alum are gradually deposited in it, easily recognizable by their octahedral shape and by their taste.

VI. The portion of matter undissolved by the caustic potash ley must now claim our attention. In general it consists of peroxide of iron, or of a mixture of peroxide of iron and sesquioxide of manganese; but it is possible also that it may contain yttria, zirconia, oxide of cerium, and even oxide of uranium. The yttria, zirconia, and protoxide of cerium are white, the peroxides of cerium and uranium are yellow, and the peroxide of iron red. The first thing to be done is to digest the whole in muriatic acid. A few white flocks commonly remain undissolved. They consist usually of silica, though in some rare cases it is possible that they may consist of columbic acid, or even of titanic acid.

We determine whether it be silica by fusing it before the blowpipe with carbonate of soda. It melts with effervescence into a colourless bead.

Columbic acid is white and tasteless as well as silica, and is equally infusible before the blowpipe per se. When heated with carbonate of soda an effervescence takes place, but the oxide neither dissolves nor is reduced. With borax it forms a colourless transparent glass, which becomes opaque by flaming, and if the proportion of oxide be large, it assumes on cooling the appearance of a white enamel. With biphosphate of soda it fuses easily, and in large quantity, into a transparent glass, which retains its transparency after cooling.

Titanic acid, when pure, is white, but it is usually combined with some peroxide of iron, which gives it a reddish-yellow colour, more or less deep according to the quantity of iron present. This substance, like silica and columbic acid, is infusible per se before the blowpipe. With carbonate of soda it fuses with effervescence and sputtering into a dull yellow transparent glass, which is not absorbed by the charcoal, and becomes white, or greyish-white on cooling. This globule has the property of crystallizing at the moment it ceases to be ignited, disengaging at the same time so much heat, that the globule ignites afresh, and even becomes white hot. The intensity of this phenomenon depends chiefly on the soda and titanic acid being exactly in the proper proportions, an excess of either ingredient greatly diminishing or entirely destroying the appearance.

With borax (on platinum wire) titanic acid fuses readily into a colourless glass, which becomes milk white by flaming. If the proportion of acid be increased, the glass turns white spontaneously on cooling. If the quantity be small, the glass becomes first yellow in the reducing flame, and when the reduction is complete it assumes a dull amethyst colour, which becomes more distinct when the bead cools. This glass is transparent, and a good deal resembles that of the oxide of manganese, acted on by the oxidizing flame, but inclines rather more to blue. With a larger portion of titanic acid the glass becomes dull yellow on charcoal in the reducing flame, and on cooling acquires so deep a blue colour that it appears black and opaque. If it be then flamed, it becomes light blue, but opaque and like enamel.

Biphosphate of soda dissolves titanic acid in the exterior flame, and converts it into a clear colourless glass. In the reducing flame the glass appears yellowish-white while hot, but on cooling it becomes at first red, and then assumes a very beautiful bluish violet colour. With too large a quantity o. acid the colour is so deep that the glass seems opaque, without having the appearance of enamel. The colour may be discharged by the exterior flame.

If the titanic acid contain iron, the violet colour derived from the protoxide of titanium does not appear, and in the reducing flame the glass assumes a red colour, similar to that developed by ferruginous tungstic acid. If these substances be in small quantity the colour becomes yellowish-red, but it does not appear till the glass begins to cool, and generally does not acquire its full intensity till the globule is perfectly cold. Such is the delicacy of this test, that when the glass contains so little titanic acid that we cannot decidedly ascertain its presence by examining the colour, we may immediately perceive it by adding iron, particularly metallic iron, when the effect is instantly and unequivocally produced. If we add a little tin to this glass, and continue the blast, the colour derived from the iron disappears, and the violet tint of the oxide of titanium re-appears. But in order to produce this effect it is necessary that the colour of the glass be not too intense; if it be, a fresh portion of the flux must be added.*

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* Berzelius on the Blowpipe, p. 74.

VII. What is dissolved in the muriatic acid is seldom an thing else than a mixture of peroxide of iron and protoxide manganese. If it contains a great excess of muriatic acid, must be evaporated nearly to dryness to drive off this exce Dilute it with water, and drop into the solution weak ammon cautiously till the excess of acid is very nearly saturated. Th is known by the colour of the liquid changing from yellow red. After this add ammonia, drop by drop, stirring the liqu after each addition, till the peroxide of iron begins to preci tate. If we now raise the temperature of the liquid (whi ought to be in a flask) to the boiling point, the whole peroxi of iron falls, while the manganese remains in solution. throwing the whole upon a filter while boiling hot, we separ the peroxide of iron, and leave the manganese in soluti The peroxide of iron must be well washed in the way abo described with boiling water.

I sometimes follow this process, which was first suggest by Sir John Herschell, but it is a method which is apt to fa unless we are very careful of the quantity of ammonia adde a very little too much throws down manganese along with th iron. The method which I usually follow was suggested b Hisinger, as a substitute for Gehlen's method of separatin peroxide of iron by means of succinate of ammonia. Drop solution of benzoate of ammonia into the saturated liquid. buff coloured precipitate falls, and the liquid becomes trans parent and colourless. The benzoate of iron (which is th buff coloured precipitate) falls more speedily if we heat th liquid, after adding the benzoate of ammonia.

The benzoate of iron is allowed to subside, the clear liqu is to be withdrawn by a sucker, and its place supplied by equal quantity of water, taking care to stir the mixture with glass rod. When the benzoate of iron has subsided to t bottom, if the supernatant liquid be colourless, the process h been properly conducted; but if the liquid be coloured, may conclude that the benzoate of iron contains an excess acid. This must be removed by dropping ammonia into t liquid (stirring it after each addition) till the colouring mat precipitates. It is needless to observe that great caution m be observed in adding the ammonia, lest we precipitate a manganese which may be in the liquid, together with benzoate of iron.

Instead of ammonia we may pour into the coloured liqu solution of sal ammoniac. The benzoate of iron will be p cipitated, while the manganese will be held in solution. We now collect the benzoate of iron on a filter, wash it with a solution of sal ammoniac, dry it, and expose it to a heat sufficiently strong to sublime the benzoic acid.

The peroxide of iron* thus obtained has a red colour, is tasteless, and dissolves in muriatic acid. The solution is a deep yellow, or almost a red. It has a very harsh astringent inky taste, and strikes a deep blue almost black with the infusion of nutgalls, and a deep blue with the prussiate of potash.

The iron being thus separated, the liquid (previously reduced by evaporation to a convenient bulk) is raised to the boiling point, and carbonate of soda being added, the manganese is thrown down in the state of a white powder, (the carbonate,) which when ignited becomes black, or, if the heat be strong, red.

It is of importance to ascertain beforehand whether the solution contain any manganese in solution. The appearance of the matter before it is dissolved in muriatic acid gives us some information. If it is dark brown, or almost black, we may suspect manganese. If it is a fine red, it consists chiefly of peroxide of iron. There is a valuable test of manganese which I frequently employ, namely, bleaching powder or chloride of lime. But care must be taken that it does not contain any excess of lime, otherwise it would throw down iron as well as manganese. A drop of solution of bleaching powder being let fall into a liquid containing manganese, occasions an immediate precipitate of reddish or brownish-red flocks. Should the colour remain unaltered, we may be sure that no manganese is present in the liquid.

The white colour of carbonate of manganese, and the change of that colour to black or red when the powder is ignited, is a sufficient character to enable us to distinguish manganese from other bodies.

If alumina and magnesia occur together in the mineral, the precipitate, together with alumina and oxides of iron and manganese, will likewise contain magnesia, which will be precipitated by the ammonia along with the alumina. In such cases we have a solution of magnesia, protoxide of manganese, and peroxide of iron in muriatic acid. The best way of

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* Benzoate of ammonia does not precepitate protoxide of iron. We must, therefore, take care to ensure the peroxidizement of the iron by digesting it, if necessary, with nitric acid.

separating these bodies from each other is the following:—Make the solution nearly neutral by evaporating it almost to dryness, and then diluting it with water till its bulk amounts to ten or twelve cubic inches. Dissolve bicarbonate of potash in water, and drop the solution into the liquid till the peroxide of iron is completely thrown down. Then filter. The liquid which passes through the filter will retain all the magnesia and oxide of manganese held in solution by the carbonic acid of the bicarbonate. These two substances, supposing them to exist together in solution, may be separated from each other, or at least the amount of each ascertained in the following manner:—

Divide the liquid into two equal portions. Into the one pour a solution of neutral chloride of lime. The whole manganese falls in the state of a red powder. Separate this powder, wash it, and expose it when dry to a red heat. Every six grains of it in this state indicate $4\frac{1}{2}$ grains of protoxide of manganese. Let the weight of the precipitate be a, then the protoxide of manganese in the half of the liquid employed $= \frac{3}{4}a = b$, and the whole oxide of manganese in the portion of the mineral examined $= \frac{3a}{2}$.

Raise the other half of the liquid to the boiling temperature, and add an excess of carbonate of soda, boil for some time, then evaporate the whole liquid to dryness in a porcelain basin, pour water on the dry residue, and digest it till every thing soluble be taken up, then throw the whole upon a filter, wash the white matter remaining on the filter, dry it and expose it to a red heat, and then weigh it. The weight will indicate one half of the magnesia contained in the original precipitate, together with one half of the manganese in the state of red oxide.

By the first step of the process we determined the half of the manganese in the state of protoxide. Now protoxide of manganese is to red oxide as 4·5 to 4·833. To find the weight of red oxide of manganese contained in our second precipitate, we say $4{\cdot}5 : 4{\cdot}833 :: b : x =$ the quantity of red oxide in the powder, and $x = \frac{4{\cdot}833b}{4{\cdot}5}$. This quantity being subtracted will leave the quantity of magnesia; and twice this weight will obviously be the whole magnesia contained in the quantity of mineral under examination.

If we are not in possession of neutral chloride of lime, we ay separate the manganese and magnesia from each other in he following manner:—Saturate the potash in the liquid with uriatic acid, and then concentrate somewhat by evaporation. ass a current of chlorine gas through the liquid till the manganese is peroxidized. Add bicarbonate of potash in slight xcess. The whole manganese falls in the state of deutoxide. ash it, dry it, and expose it to a dull red heat. It will ecome perfectly black, and every five grains of it indicate 4·5 rains of protoxide of manganese. Let the weight of black wder obtained in this manner be *a*, the protoxide of mannese in the liquid will be $\frac{9a}{10}$.

Instead of throwing down the magnesia by carbonate of da, we may add to the liquid thus freed from manganese, osphate of soda and caustic ammonia, or biphosphate of monia. The magnesia is precipitated in the state of monia-phosphate of magnesia. When this salt is exposed a red heat, it loses its ammonia and its water of crystallizaon, and there remains biphosphate of magnesia, every $11\frac{1}{2}$ rains of which are equivalent to $2\frac{1}{2}$ grains of magnesia. Let e weight of biphosphate of magnesia obtained be *a*, then the hole magnesia contained in the precipitate $= \frac{5a}{23}$.

VIII. There are certain minerals which contain yttria, rconia, and oxides of cerium and uranium. Now, when ese bodies happen to be present, they will be thrown down the caustic ammonia, together with the alumina, iron, and anganese, the mode of separating which has just been inted out. It may be proper therefore to make a few servations on the mode of detecting yttria, zirconia, and ides of cerium and uranium, when they occur.

1. Yttria has been hitherto met with only in about eight inerals (as may be seen in the first part of this work), the ecific gravity of which (if we except *orthite* and *pyrorthite*), not less than 4·15, nor greater than 5·88. Yttria is most mmonly accompanied by oxide of cerium; and the characrs of these bodies are so nearly alike, that it is not easy to parate them from each other. Let us suppose that the prepitate after digestion in caustic potash, consists of a mixture yttria, oxide of cerium, and oxide of iron. Dissolve it in uriatic acid, and into the solution place a mass of sulphate potash, so that a portion of it shall stand higher than the

surface of the liquid, and the quantity of which is so grea that the liquid is incapable of dissolving it. Leave the mixture in this state for twenty-four hours. Oxide of cerium has the property of forming a compound salt with sulphate o potash, which is insoluble in a saturated solution of sulphat of potash, whether the liquid contain an excess of acid or not The oxide of cerium will be precipitated in the state of thi compound salt. Let it be collected on a filter, and washe with a saturated solution of sulphate of potash. The liqui by this process is freed from oxide of cerium.

It still contains yttria and peroxide of iron; let it be neutralized and the iron thrown down by benzoate of ammon by the method already explained.

Nothing now remains in solution but the yttria, which to be precipitated by caustic potash or soda.

The oxide of cerium thrown down in the state of potash-sulphate of cerium is a granular powder, white if the cerium be in the state of protoxide, but lemon-yellow when the peroxide of cerium is present. Dissolve it in water, add an excess of caustic potash or soda, and digest for some time on the sand-bath. The oxide of cerium is thrown down. When washed, dried and ignited, it is always in the state of peroxide of cerium, and has a cinnamon-brown or tile-re colour.

2. Protoxide of cerium, while in the state of an hydrat is white, but when dried in the air it becomes yellow. ignition it is peroxidized. The protoxide dissolves rea in acids and the solution is colourless. The solution of peroxide is yellow or reddish-yellow. When muriatic is digested on peroxide of cerium, chlorine is exhaled, an solution becomes gradually colourless by the conversion peroxide into protoxide.

The solution of protoxide of cerium exhibits the fol phenomena with re-agents:

(1.) Potash or soda throws down a bulky white pre which does not re-dissolve though the potash be excess.

(2.) Ammonia acts precisely as potash does.

(3.) Carbonate of potash, bicarbonate of potash bonate of ammonia throw down a white bulky which is soluble in an excess of the precipitatin but the whole of the precipitate is again thrown the liquid is raised to the boiling temperature.

(4.) Phosphate of soda throws down a white precipitate, sily soluble in acids.

(5.) Oxalic acid throws down a white bulky precipitate, rovided there be not too great an excess of acid in the uid,) which dissolves in a great excess of muriatic acid.

(6.) If the solution be not too dilute, sulphate of potash rows down a crystalline precipitate,* very difficultly soluble water and not at all in a solution of sulphate of potash.

(7.) Prussiate of potash throws down a white precipitate.

(8.) Sulphuretted hydrogen occasions no precipitate, but lphohydrate of ammonia throws down a white powder.

(9.) Before the blowpipe, in the outer flame, oxide of rium melts with borax or biphosphate of soda into a *red* ad, but the colour diminishes as the bead cools and at last vanishes. In the inner flame the glass formed is colourless.

It is unnecessary to state the phenomena of the solution of roxide of cerium, because the peroxide by solution in muri-c acid and digestion can easily be brought into the state of otoxide.

3. Yttria, while in the state of a hydrate is white, but by nition its colour is changed into a dirty yellowish white. It solves readily in acids, and the solution is colourless. It hibits the following appearances with re-agents:—

(1.) Caustic potash, or soda, throws down a white bulky ecipitate, not redissolved by adding an excess of the alkali.

(2.) Ammonia exhibits the same phenomena.

(3.) The alkaline carbonates throw down a bulky precipi-te which is redissolved in an excess of the precipitant. The carbonate of potash redissolves the precipitate more readily an the carbonate. Carbonate of ammonia does not redis-lve yttria so easily as it does glucina.

(4.) Phosphate of soda throws down a white precipitate, hich is redissolved by muriatic acid; but the precipitate pears again when the liquid is boiled.

(5.) Oxalic acid throws down a bulky white precipitate uble in muriatic acid.

(6.) Sulphate of potash occasions, after a considerable in-val of time, a white precipitate, which is redissolved by the dition of water, even when undissolved sulphate of potash present.

(7.) Prussiate of potash throws down a white precipitate.

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* The precipitate does not fall immediately, but after an interval of time.

(8.) Sulphuretted hydrogen occasions no precipitate, but sulphohydrate of ammonia throws down yttria.

(9.) Yttria can scarcely be distinguished from the other earthy bodies by the blowpipe.

4. Zirconia is nearly as scarce as yttria. Hitherto (as may be seen in the first part of this work) it has been found only in five species of minerals, all of which, except the *zircon* or *hyacinth*, are very rare. It has a yellowish colour while in the state of a hydrate and dissolves readily in acids; but when it is deprived of its water by ignition it assumes a white colour and becomes insoluble in acids, though by long digestion in concentrated sulphuric acid we may obtain a solution of it.

The solution of zirconia in nitric or muriatic acid is colourless, and however carefully neutralized, always reddens vegetable blues. It exhibits with reagents the following phenomena:

(1.) Potash, or soda, throws down a bulky white precipitate, which is not redissolved by adding the alkali in excess.

(2.) Ammonia produces exactly the same effect.

(3.) The alkaline carbonates or bicarbonates throw down bulky white precipitates, which are redissolved by an excess of the precipitant. Carbonate of ammonia seems to be most powerful in redissolving such precipitates.

(4.) Phosphate of soda throws down a bulky white precipitate.

(5.) Oxalic acid throws down a bulky white precipitate, redissolved by adding muriatic acid to the liquid.

(6.) Sulphate of potash throws down in a short time a white precipitate, which is redissolved by the addition of a considerable excess of muriatic acid; but if the precipitate has been thrown down from a hot solution; it is insoluble both in water and in acids.

(7.) Prussiate of potash throws down a white precipitate.

(8.) Sulphuretted hydrogen occasions no change, but sulphohydrate of ammonia throws down a bulky white precipitate.

Thus zirconia is distinguished from alumina and glucina by its insolubility in potash: from yttria, because after being precipitated hot by sulphate of potash, it is insoluble in water and even in acids; whereas the precipitate of yttria by the same reagent is soluble in a considerable quantity of water. It may be distinguished also from yttria by this property after ignition it is insoluble in muriatic acid, whereas yttria after ignition dissolves readily in that acid. Zirconia is easil distinguished from oxide of cerium, because the latter when ignited becomes tile red, whereas zirconia becomes white. Before the blowpipe zirconia does not form a coloured glass with borax or biphosphate of soda, unless it be contaminated with iron.

I shall, in a subsequent part of this treatise, give an example of the mode of analyzing a mineral containing zirconia. There is considerable difficulty in separating zirconia and oxide of iron from each other, when they happen to be present in the same mineral.

5. Thorina is so rare that there is little chance of any mineral containing it coming in the way of the young analyst. shall therefore pass it over at present, and give hereafter an xample of the mode of analyzing a mineral containing this ubstance.

6. Oxide of uranium is easily recognised by the yellow olour which it gives to solutions containing it. Prussiate of otash throws it down of a dark brown colour. If the solution f uranium be neutral, the infusion of nutgalls gives the same ark reddish-brown precipitate; but if there be an excess of cid in the liquid, no effect is produced by this reagent. Oxide f uranium dissolves in an excess of carbonate of ammonia; he solution of it is yellow, and if concentrated it deposits bundance of crystals of ammonia-carbonate of uranium. These characters will enable the young analyst to recognise his oxide when it happens to be present in any mineral, which, however, is a rare occurrence. I shall hereafter give an example of the mode of analyzing a mineral containing this oxide.

CHAP. III.

METHOD OF DETECTING AND SEPARATING FIXED ALKALIES.

THE three fixed alkalies, *potash*, *soda*, and *lithia*, are pretty frequent ingredients of minerals, as may be seen by inspecting the table prefixed to the first part of this work. Potash was first discovered in the mineral kingdom by Klaproth, in his analysis of the *Leucite*, published in 1795. Soda was soon after detected by Dr. Kennedy in basalt, and lithia was discovered in petalite by Arfvedson in 1818. The two first of these are found in the mineral kingdom much more frequently than the third. Various methods have been contrived to detect and separate these bodies. We have reason to suspect their existence when, after having made an analysis of a mineral, the weight of the constituents detected comes considerably (more than 2 per cent.) short of the mineral subjected to analysis.

The method which I employ in such cases to detect and separate potash and soda, is the following:—Reduce a quantity of the mineral (25 grains for example) to powder. By a previous analysis the quantity of silica contained in this portion is known. For every grain of such silica weigh out 2·375 grains of fluor spar, previously reduced to a fine powder. Mix the fluor spar and the pounded mineral intimately in a platinum crucible, and pour upon the mixture a quantity of strong sulphuric acid sufficient to convert the whole into a pulp. Put the crucible on a sand bath, and expose it to a heat gradually raised to 400°. Then heat it to redness, and keep it red hot till the whole excess of sulphuric acid is driven off. Digest the residue in water till every thing soluble is taken up. Concentrate this aqueous solution on the sand-bath, and while it is hot add a little oxalate of ammonia to decompose a little sulphate of lime which it contains. Separate the clear liquid from the oxalate, and for the greater security add a little carbonate of ammonia to it. After the precipitate has been removed, evaporate the liquid to dryness in a platinum basin, and expose the residue to a red heat to drive off the ammoniacal salts. The matter remaining will be an alkaline sulphate.*

Dissolve this sulphate in water, and let fall into it a few drops of an alcoholic solution of chloride of platinum. If the alkali be potash a yellow coloured precipitate falls, but no precipitate will appear if the alkali be soda.

Should a precipitate appear, but indicating only a portion of the alkali and not the whole, then the conclusion to be drawn is, that the alkali in the mineral is a mixture of potash and soda. To determine how much of each is present we must proceed in the following way:—The alkaline sulphates are to be dissolved in water, and by means of chloride of barium cautiously added they are to be converted into

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* If the mineral contain magnesia, some of that substance may be present. It must be separated by the methods already detailed, before we obtain the alkaline sulphate.

chlorides. Evaporate these chlorides to dryness and determine their weight. Mix them with 3¼ times their weight of soda-muriate of platinum in crystals. Dissolve the mixture in a very small quantity of water, and evaporate to dryness in a very gentle heat, and digest the dry residue in alcohol of the specific gravity 0·896. This dissolves every thing but the potash-muriate of platinum which remains in the state of a yellow powder. Bring the undissolved portion upon a weighed filter, and wash it with weak alcohol. Dry it in a gentle heat till it ceases to lose weight. The weight of this salt gives the potash which it contains, every 26 grains of it indicating 6 grains of potash. If we convert this potash into chloride, recollecting that 6 potash is equivalent to 9½ chloride, and subtract the amount from that of the whole chloride originally weighed, the remainder gives us the chloride of sodium, from which the quantity of soda is easily determined by calculation.

Should no precipitate fall when the tincture of chloride of platinum is dropt into the solution of alkaline sulphate, we may then add a little alcohol to the solution, and set it aside for twenty-four hours. If it contains sulphate of soda, that salt will shoot out into crystals, and the shape of the crystals will readily indicate the nature of the salt.

If we suspect the alkali in the sulphate to be lithia, or to contain lithia, the easiest mode of proceeding, is to add a little sulphuric acid, so as to convert the sulphate into bisul-hate. This bisulphate is to be digested in alcohol. If it be isulphate of lithia it will be wholly dissolved, while the isulphate of potash or of soda, should either be present, will emain undissolved. The alcoholic solution of bisulphate of thia burns with a red coloured flame which is characteristic f this alkali.*

Evaporate the alcoholic solution to dryness, and expose it a red heat, having previously neutralized the excess of acid y ammonia. We thus convert it into sulphate of lithia mposed of

Sulphuric acid	5
Lithia .	1·75
	6·75

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* Dr. Turner has shown that the presence of lithia in a mineral may be tected by the blowpipe, by fusing it with a little alkali to set the lithia at erty. It then betrays itself by giving a red tinge to the flame.

Let its weight be a, the weight of lithia which it contains is $\frac{1{\cdot}75\,a}{6{\cdot}75}$, or $\frac{7a}{27}$.

Should any doubt exist about the lithia, we may remove it by converting the sulphate into muriate. For this purpose weigh it, and add as much chloride of barium as will throw down all the sulphuric acid, on the supposition that it is sulphate of lithia. Let the weight of the sulphate of lithia be a, then $6{\cdot}75 : 13 :: a : \frac{13\,a}{6{\cdot}75}$ = the quantity of anhydrous chloride of barium required. Or if we take crystals of chloride of barium the weight will be 15·25 instead of 13, and the quantity $\frac{15{\cdot}25\,a}{6{\cdot}75}$, or $2{\cdot}44\,a$. Now filter the liquid, and let a drop of sulphate of soda fall into it. If the salt was sulphate of lithia no precipitate will fall, but if it was sulphate of soda, or contained sulphate of soda, a precipitate will still appear. Determine by cautious addition how much sulphate of soda is requisite to throw down the whole barytes which has been added in excess. If the salt was pure sulphate of soda, the quantity of sulphate of soda necessary to throw down the whole excess added, will be such that the sulphate of barytes thrown down by this second dose of sulphate of soda will form a salt weighing 0·248 of the sulphate of barytes first thrown down.

It is easy from the weight of sulphate of barytes obtained to deduce the proportion of soda and lithia in the original sulphate.

Let the weight of the alkaline sulphate be a, and let the sulphuric acid obtained be ten or two atoms. Then $a - 10$ = alkali in sulphate = m.

1. $m = 4x + 1{\cdot}75\,y$ $\quad x$ = atoms soda, y = atoms lithia.
2. $x + y = 2$ as the acid was 2 atoms.

$$x = \frac{m - 1{\cdot}75\,y}{4}$$

$$x = 2 - y$$

$$\frac{m - 1{\cdot}75\,y}{4} = 2 - y \text{ and } y = \frac{8 - m}{2{\cdot}25}$$

y being thus found gives us x, and the weight of the lithia in the sulphate is $1{\cdot}75\,y$, while that of the soda $4\,x$.

Muriate of lithia is a deliquescent salt. Lithia is thrown down from any of its saline solutions by means of carbonate of ammonia, in the state of a white powder.

If lithia and potash exist together in a mineral, they may e separated from each other exactly in the way by which otash and soda were separated in page 387.

Another mode of detecting an alkali in minerals, which is ery frequently employed by mineralogists, is to make use f carbonate of barytes. The pulverized mineral is mixed ith five or six times its weight of carbonate of barytes, and xposed to a red heat for an hour or an hour and a half in a latinum crucible. The whole is then dissolved in muriatic cid, and the silica separated in the usual way. The earths d metallic oxides (including the barytes) are then thrown wn by carbonate of ammonia. The filtered liquid is eva- rated, and when concentrated and hot, a little oxalate of nmonia may be added to throw down any lime which might cidentally remain in the liquid. The whole is now eva- rated to dryness, and the residual salt is to be cautiously ated till the whole of the ammoniacal salt is driven off. hat remains is an alkaline muriate, or a sulphate if the rytes (as is often practised) had been thrown down by lphuric acid.*

Another method, first proposed by M. Berthier, is to mix e pounded mineral with twice its weight of nitrate of lead, d its own weight of carbonate of lead, both in the state of a e powder. This mixture is put into a small platinum ucible covered with a lid. This crucible is enclosed in other also covered with a lid.† The crucibles are heated an ordinary furnace, and kept red hot only for a quarter of hour. Before it is quite cold, the crucible is reversed ove water, and the fused mass by tapping the bottom is de to fall into that liquid. It falls down into numerous gments which makes it easily attackable by acids. Boil it nitric acid, taking care to reduce all the fragments to fine wder. Every thing is dissolved except the silica, which is arated in the usual manner. The oxide of lead is thrown wn by sulphuric acid, and we ensure its complete separation

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* If the mineral contain magnesia, a portion of it might remain in the e of sulphate, as carbonate of ammonia is not a good precipitant of it. such a case the sulphate must be weighed, and the magnesia being arated in the usual manner and weighed, we must deduct the weight of ydrous sulphate of magnesia from the original quantity, the remainder be the alkaline sulphate.

† All these precautions are to guard against the reduction of the lead, ch would occasion the destruction of the platinum crucible.

by the addition of a little sulphuretted hydrogen. The earths and metallic oxides are then thrown down by carbonate of ammonia. The residual liquid is evaporated to dryness, and being treated as already described, the alkaline sulphates are obtained in a separate state.*

CHAP. IV.

METHOD OF DETERMINING THE ACIDS IN MINERALS.

In the preceding chapters the methods of detecting the different bases which occur in stony bodies has been pointed out. But with the exception of silica nothing has been said about the acids. By inspecting the table at the commencement of the first part of this work, it will be seen that minerals are in fact salts, composed of one or more acids in combination with one or more bases. By far the most common acid in minerals is silica, and the method of detecting and separating it has been already described. But there are at least twelve other acids which may occasionally be present, and we shall in this chapter point out the methods of detecting their presence.

To determine whether a mineral contain any acid, reduce a portion of it to powder, and fuse it either in a platinum crucible or by the blowpipe with twice its weight of carbonate of potash or carbonate of soda. Digest the fused mass in water till every thing soluble be taken up. Fusion with the carbonates of the fixed alkalies decomposes all the salts containing a fixed acid. Hence the water employed to digest the fused mass will contain an acid (if any was present) combined with the alkali employed. Saturate this alkali with acetic acid, and add to the neutral liquid a few drops of acetate or nitrate of lead. If an acid be present a white precipitate will appear.† Hence the absence of every precipitate when the salt of lead is added, is a proof that the mineral under examination contains no other acid than silica. Suppose that by this method the existence of an acid is detected, the next thing to be done is to determine what that acid is.

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* Ann. de Chim. et de Phys. xvii. 28.

† Nitric acid occasions no precipitate. The method of detecting it will be shown afterwards.

Fuse a portion of the alkali containing the acid on ɔal by the blowpipe, and put the fused bead in a drop ter placed on a piece of polished silver. If the acid was *ılphuric*, a black spot of sulphuret of silver will be pro- . Bright copper will also serve for the same purpose. place the globule of the fused salt on cudbear paper it hange its colour to purple.

ve suspect the acid to be the *muriatic* or *chlorine*, we put a plate of polished silver a drop of the solution of sul- l peroxide of iron, or of the sulphate of copper; into this ve let fall a little of the alkali containing the acid in on. If it be the muriatic or chlorine, a spot of black de of silver will be produced.*

If the acid be the *phosphoric*, the alkali containing it, ;aturation with acetic acid, gives a sulphur yellow preci- with nitrate of silver, which no other acid does.†

e precipitate which it gives with lead crystallizes before owpipe.

ɔhs remarks that if a mineral containing phosphoric acid luced to powder, immersed in sulphuric acid, and then ed to the action of the blowpipe, it will tinge the flame luish-green colour. The phosphate of alumina commu- s this colour without the assistance of sulphuric acid.‡

rzelius gives the following method of discovering phos- ; acid in a mineral. Fuse the mineral in question with .c acid before the blowpipe, and when the fusion is .ete, plunge the end of a small steel wire, rather longer :he diameter of the globule, into it, and heat it in a good ıng flame. The iron becomes oxidized at the expense e phosphoric acid; hence borate of iron and phosphuret n are produced. The latter fuses at a pretty high tem- ıre, and at the same time the assay, which had spread over the whole length of the wire, resumes the globular As the globule cools, an appearance of ignition is ally seen near its base, arising from the crystallizing of ıosphuret of iron. Remove the globule from the charcoal, it in a piece of paper, and strike it gently on the anvil

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is well known that chloride of silver is precipitated white, but it ıs on exposure to the light; but the black colour of chloride of silver ed in this way, is independent of the light.

ıe arsenious, indeed, gives a yellow precipitate with nitrate of silver, ;an scarcely occur in stony minerals.

:hweigger's Jour., xxiv. 130.

with the hammer, to separate the phosphuret of iron, which we find in the form of a brittle metallic globule, attractable by the magnet, and having a steel-coloured fracture. Its brittleness depends upon the proportion of the iron; it may sometimes be a little flattened under the hammer. If the assay contain no phosphoric acid, the steel wire will burn only at the ends which project beyond the globule, preserving elsewhere its form and brilliancy. Since four or five per cent. of phosphoric acid are insufficient to fuse a mass of iron as large as the experiment requires, it follows that a proportion not exceeding that quantity cannot be discovered by the blowpipe.*

4. *Arsenic acid* constitutes one of the ingredients of several minerals, as may be seen by inspecting the table at the beginning of the first part of this work. The presence of this acid is easily detected, by exposing a small portion of the mineral containing it, mixed with carbonate of soda, to the reducing flame of the blowpipe on charcoal; a white smoke is exhaled, having the well known smell of arsenic.

The arseniates resemble the phosphates in almost all their properties. Like them the alkaline arseniates are soluble in water, while the arseniates of the alkaline earths, and of the earths and metallic oxides, are insoluble. A little sulphuretted hydrogen dropt into a solution of a soluble arseniate strikes a a yellow colour, and the addition of a few drops of muriatic acid occasions a yellow precipitate of sulphuret of arsenic. The insoluble arseniates are easily soluble in muriatic or nitric acid, and the solution, when acted on by sulphuretted hydrogen, gives the same yellow colour and precipitate.

Chlorides of barium and calcium, and barytes, or lime water, occasion a white precipitate when dropt into a solution of an arseniate. These solutions are soluble in nitric and muriatic acid. They dissolve also in sal ammoniac, as is the case with the same precipitates induced in the phosphates. But the arsenical precipitates are more easily dissolved in sal ammoniac than the phosphates; on the contrary, they are more difficultly soluble than the phosphates when the solution contains free ammonia.

The yellow precipitate produced in solutions of arseniates by sulphuretted hydrogen, is soluble in sulpho-hydrate of ammonia. The same thing happens with the precipitate produced by the same reagent in solutions of peroxide of tin:

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* Berzelius on the Blowpipe, p. 129.

nce it is possible that the two may be confounded by a reless experimenter.

5. The presence of *boracic* acid in minerals is indicated by e green colour which they give during fusion to the flame the lamp or candle employed. Gay-Lussac has observed at a solution of boracic acid changes the colour of turmeric per to red, like an alkali.* Borax, to which sulphuric acid s been put, does so; and the same holds with a bead of soda ntaining boracic acid.

The most certain test of boracic acid in a soda bead, &c., is add sulphuric acid to it, and then spirit of wine, the flame f which will be coloured green if boracic acid be present.

Professor C. G. Gmelin of Tubingen, who devoted several ears to the analysis of the tourmalin, has adopted the follow- g method of separating boracic acid from those minerals hich contain it. The mineral must be reduced to a fine wder, mixed and ignited with an alkaline carbonate. The ited mass is to be digested in water to separate the alkaline ich now holds the boracic acid in combination. The alka- e liquid thus obtained is to be exactly saturated with muriatic d. Muriate of lime, and then caustic ammonia, being added he neutral liquid, the boracic acid precipitates in combina- with lime.

The quantity of boracic acid in combination with the lime y be determined in the following manner:—Expose the te of lime to a red heat, and then ascertain its weight. it with its own weight of pure fluor spar in a platinum ible, and reduce the whole mixture to a pulp by the tion of a sufficient quantity of sulphuric acid. Digest this ture for some time on the sand-bath, then expose it to a heat, and keep it at that temperature till all the excess of huric acid be driven off. Nothing will remain but sulphate me. The boracic acid having been driven off in combina- with the fluoric acid, leaving the lime formerly in com- ation with both these acids in the state of an anhydrous phate.

Now 9·5 fluor spar, when decomposed by sulphuric acid, omes 17 sulphate of lime; we can, therefore, easily find much of the sulphate of lime obtained by our process was ived from the fluor spar. Let the weight of fluor spar

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* Ann. de Chim. et de Phys. xvi. 75.

employed $=a$. We have $9·5 : 17 : : a : \frac{17\,a}{9·5} =$ sulphate o lime derived from the fluor spar $= b$.

If we subtract b from the total weight of the sulphate lime, the remainder $(= c)$ will be the sulphate of lime derive from the borate of lime. But sulphate of lime is composed

Sulphuric acid, . .	5
Lime, . . .	3·5
	8·5

Consequently, $8·5 : 3·5 : : c : \frac{3·5\,c}{8·5} = d =$ the weight of t lime derived from the borate of lime examined. Now, if subtract d from the quantity of borate of lime employed in t experiment, the remainder will be the weight of boracic ac originally combined in this borate.

6. The presence of *chromic acid*, or *chromium*, in any stat is easily discovered by the yellow colour which carbonate potash, or soda, acquires when fused with it. If this alkalin solution be saturated with acetic acid, it gives a fine orang precipitate with acetate of lead, and a red precipitate wit nitrate of silver.

Chromate of potash, or soda, fused on a plate of clay, leave green oxide of chromium.

When a mineral, or salt, containing chromic acid, is fuse with borax, or biphosphate of soda, before the blowpipe o charcoal, a glass bead is obtained, of a fine emerald gree colour, whether the fusion be performed by means of the out or inner flame. This colour appears to most advantage whe the bead is cold. It is obvious that if the chromic acid be i combination with a metallic oxide capable of giving a dee colour to the glass, the colour of the bead may be considerabl modified. Thus, when chrome-iron ore is fused with borax, biphosphate of soda, the characteristic colour of iron is onl apparent while the assay is hot; but when, on cooling, i colour disappears, then the fine grass green of the chromiu is developed.

If a chromate and a chloride be ground together, mix with concentrated sulphuric acid, and heated, an effervescen takes place and beautiful red fumes are disengaged, constitu ing, when condensed, the chlorochromic acid of Dr. Thomso

When a chromate is mixed with muriatic acid and heate lorine gas is disengaged, easily recognised by its smell and so by its colour. The experiment may be made in a crystal ass tube shut at one end. The muriatic acid assumes durg the process, a dark green colour, because oxide of chroium is formed and dissolved.

When chromic acid exists in solution, it may be precipitated nitrate of lead, which throws it down in the state of chroate of lead, even when the liquid contains an excess of acid. ery 20·5 grains of this chromate when dried by ignition, is uivalent to 6·5 grains of lead. Or the chromic acid is 0·317 the weight of the chromate of lead obtained.

7. *Molybdic* acid scarcely occurs in the mineral kingdom, cept in combination with oxide of lead, constituting molybte and trismolybdate of lead.

This mineral before the blowpipe on charcoal, decrepitates d acquires a brown yellow colour, which disappears on ling. It then fuses and is absorbed, leaving on the surface bules of reduced lead. By washing the absorbed part, we tain a mixture of globules of lead and metallic molybdenum, ich has the metallic lustre, but is neither malleable nor ible. With borax, in the exterior flame, it fuses readily o a colourless glass. In the interior flame we obtain a nsparent glass, which all of a sudden becomes dark brown d opaque. With biphosphate of soda it fuses readily, and e obtain a green glass if the quantity of molybdate be small, black opaque glass if the quantity be considerable.

To separate the molybdic acid from oxide of lead, or indeed ny oxide with which it may be combined, we must dissolve he molybdate in any acid except the nitric. To the solution an excess of ammonia is added, and the whole is digested in sulphohydrate of ammonia. The oxide is precipitated in the form of a sulphuret, while the molybdic acid is retained in solution by the sulphohydrate. The sulphurets are filtered off, and the bisulphuret of molybdenum precipitated by muriatic acid. This sulphuret contains $\frac{3}{5}$ths of its weight of molybdenum, and every 10 grains of it are equivalent to 9 grains of molybdic acid; or the molybdic acid is equivalent to $\frac{9}{10}$ths of the bisulphuret of molybdenum obtained.

The sulphuret may be converted into molybdic acid by cautious roasting and subsequent solution in caustic ammonia, from which it may be thrown down by muriatic acid.

When this acid is heated in a close vessel, it fuses, and the fused mass on cooling assumes a light yellow colour and a crystallized texture. In an open vessel it smokes and sublim in a moderate temperature.

It is very little soluble in water, though the aqueous sol tion reddens litmus paper. But it dissolves readily in s lutions of the fixed alkalies or of their carbonates. T solution is transparent and colourless, and the resulting sa readily soluble in water. But all the earthy and oxide sa of molybdic acid are insoluble. Hence the solution of alkaline molybdate is precipitated by almost all the earthy metallic acid salts.

Nitrate of lead throws down a *white* precipitate, nitrate mercury, a *yellow*, nitrate of silver, a *white* precipitate, sol ble in a great deal of water, and still easier in nitric acid ammonia. In like manner, the salts of peroxide of iron thro down a yellow precipitate, which dissolves in a great exce of water. The chlorides of calcium and barium throw dow white precipitates also soluble in much water, especially th caused by the former of the two. But if we neutralize tl excess of acid present with ammonia, a precipitate appea which is not rendered soluble by adding more water.

Molybdic acid is easily soluble in acids unless it has bee ignited, by which process it is rendered insoluble in most ac bodies. But if we boil a mixture of cream of tartar ai ignited molybdic acid in water, a solution is obtained.

8. *Tungstic acid*, occurs in the mineral kingdom united lime and to oxide of lead. The tungstic acid may be detect in either of these minerals, by fusing a globule of them wi biphosphate of soda before the blowpipe. The tungstate lime when so treated in the interior flame, assumes a gre colour which it retains while hot, but which turns to a fi blue on cooling. With tungstate of lead treated in the sai way, we obtain at once a blue glass, sometimes with a sha of green.

Tungstic acid may be separated from those oxides w which it is combined, by dissolving the salt in an acid a then adding an excess of sulphohydrate of ammonia. T base is thrown down in the state of sulphuret, but the s phuret of tungsten remains in solution. The sulphuret tungsten is thrown down by muriatic or nitric acid. It washed and roasted, which converts it into tungstic acid.

The tungstic acid is separated from lime by fusing t mineral with carbonate of soda. The tungstic acid combi with the soda. It may be washed off and neutralized w muriatic acid added in excess. The tungstic acid precipitates and may be washed, dried, and weighed.

Tungstic acid has a yellowish colour, and when heated becomes lemon yellow. It is fixed, and does not dissolve in water, yet it reddens moist litmus paper.

It forms with the alkalies, salts which are colourless and soluble in water. After ignition it is much more difficult to dissolve it in alkalies, than it is to dissolve molybdic acid in the same state.

Acids when dropt into solutions of the alkaline tungstates occasion precipitates. Sulphuric, nitric, and muriatic acids throw down white precipitates, which are combinations of tungstic acid with the precipitating acid. Phosphoric acid throws down a precipitate soluble in an excess of phosphoric acid. Oxalic, tartaric, and citric acids, occasion no precipitates. Acetic acid throws down a precipitate which is not soluble in an excess of the acid.

The compounds of tungstic acid, with the earths and metallic oxides (tungstate of magnesia excepted) are insoluble in water. Hence it happens that the alkaline tungstates are precipitated by most of the earthy and oxide salts. Chloride of barium, chloride of calcium, nitrate of lead, and nitrate of silver, throw down white precipitates which are not re-dissolved by the addition of much water.

If we put a little alkaline tungstate, with a fragment of tin, into a drop of muriatic acid, white flocks at first make their appearance, which gradually acquire a blue tinge, and a deep blue colour surrounds the tin globule.

9. To detect the presence of *fluoric acid* is attended with considerable difficulty, and yet is very important, because this acid enters as a very frequent constituent into the composition of minerals, as may be seen by inspecting the first part of this work.

Reduce the mineral to powder, and moisten it in a watch glass with muriatic acid; let it remain a few seconds, and then rub a piece of brazil wood paper with the mixture. If fluoric acid be present, the paper assumes a fine yellow colour.* But this method does not always answer.

When fluoric acid exists in a mineral in small quantity, in

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* Bonsdorff, to whom we owe this fact, found that fluoric, phosphoric, and oxalic acids, render brazil wood paper yellow. Some of the other acids, when dilute, give a yellow tinge to this paper, but less lively, and much more slowly.

combination with a weak base and a minute portion of water, we have only to put a little of it into a tube closed at one end, and having a small slip of paper suspended in it, moistened with the infusion of brazil wood. Heat being applied, disengages fluosilicic acid, an unpolished ring of silica makes its appearance on the glass at a little distance from the assay, and the lower end of the paper becomes yellow.

If the mineral contain a great deal of fluoric acid, let it be mixed with biphosphate of soda, previously fused and put into an inclined open tube, near the lower end, so that a part of the current of air which feeds the flame may enter the tube. Heat the mixture by means of a spirit lamp. Fluoric acid vapour is formed, which fills the tube, and may be distinguished both by its peculiar odour, and by its corroding the glass, which becomes dull through its whole length, and particularly in those places where the vapour condenses.

To determine the quantity of fluoric acid, or fluorine, in a mineral, composed of fluorine and a metal, as in fluor spar, the best method is to reduce a determinate weight of the mineral to powder, and to make it into a paste with concentrated sulphuric acid in a platinum crucible. Heat is then applied and gradually raised to ignition. When the whole fluoric acid, and the excess of sulphuric acid, has been driven off, nothing remains but a sulphate of lime. From the weight of this sulphate the weight of the calcium which it contains is easily deduced, and subtracting this weight from that of the original mineral employed the remainder gives the fluorine in the mineral.

10. *Iodic acid* and *hydriodic acid* have scarcely yet been found in the mineral kingdom. They may be detected when they do occur by the following method:—Fuse oxide of copper with biphosphate of soda into a dark green globule, then add the assay, and heat the whole before the blowpipe. The flame (if the acids be present) is coloured with a *superb deep green*, quite different from the pale green communicated by boracic acid.

When the same process is followed with a muriate, the flame has a fine *blue inclining to purple.*

Most of the compounds formed by iodic acid with bases, except the alkaline iodates, are insoluble, or very sparingly soluble in water. When an iodate is heated in a small retort, oxygen is given out, and the iodate is converted into an iodide.

When an iodide is heated with concentrated sulphuric acid in a glass tube closed at one end, it gives out iodine, which fills the cold part of the tube, and is easily recognised by its violet colour. This process conducted in a porcelain vessel, will enable us to determine the quantity of iodine disengaged. The iodide is converted into a sulphate combined with the oxide of the base. The quantity of this oxide, and consequently the weight of the base in the iodide may be determined, and this weight, subtracted from that of the original iodide, gives the weight of iodine disengaged.

11. Neither *selenic* nor *selenious* acid has hitherto been met with in the mineral kingdom. Should a selenite, or seleniate, or a seleniet, occur, it is easy to recognise the presence of selenium in them by the blowpipe. For when such a compound is heated before the blowpipe in the reducing flame, it emits an exceedingly strong odour of decayed horse radish. By this odour a very minute quantity of selenium may be detected.

When selenium is contained in a solution, as selenious acid, the best way of determining its quantity is by means of sulphurous acid. We first acidulate the liquid by adding some muriatic acid, then a solution of sulphite of ammonia is mixed with it. The selenium precipitates in the form of a cinnabar red powder which remains long suspended. But if the liquid be made to boil, the selenium unites into a very small bulk, and becomes black. If the addition of a fresh portion of sulphite of ammonia occasions no farther precipitation, we may conclude that the whole selenium is thrown down. We have then only to collect and wash it on a weighed filter, in order to determine its weight.

If nitric acid exist in a solution containing selenious acid, the selenium cannot be precipitated till the whole of that acid is destroyed. To accomplish this, place the solution on the sand bath, and add muriatic acid as long as chlorine continues to be disengaged. When the nitric acid has been destroyed in this way, we may proceed as above directed to separate the selenium.

12. *Nitric acid* is not a frequent ingredient in the mineral kingdom. It exists however in a few salts, as nitrate of soda and nitrate of potash. All fusible nitrates detonate with charcoal. Those which do not fuse are to be heated till they are rendered quite dry, and then being put into a glass tube shut at one end, they are to be gradually raised to a red heat.

The tube soon becomes filled with the orange yellow vapour of nitric acid.*

CHAP. V.

METHOD OF DETERMINING THE WEIGHT OF THE FIXED CONSTITUENTS OF STONY MINERALS.

SINCE the introduction of the atomic theory into chemistry, the number of individuals who have occupied themselves with the analysis of minerals has become very considerable, and it has sometimes happened that persons little accustomed to precise experiments have deceived themselves by the application of this theory to inaccurate results. It is necessary to be on our guard against this mode of proceeding, and never to attempt to determine the atomic constituents of a mineral till we are quite sure of the accuracy of our results, both as regards the nature and quantity of each constituent. We should also be at great pains in selecting our specimens for analysis. How accurate soever our experiments may be, we can deduce no valuable consequences from them, if the specimens selected for analysis were impure, or consisted of more than one mineral species mechanically mixed together. The specimens selected for analysis should be quite pure, and if possible in crystals.

Klaproth, to whose labours we are chiefly indebted for contriving and systematizing the methods of analyzing minerals, usually subjected 100 grains of the mineral to experiment; but now that our apparatus is simplified and improved, and our methods brought to precision, we can obtain exact results though we analyze a much smaller quantity. By employing a small quantity of mineral for analysis instead of a large, we save a good deal of time and expense, both of which, to the practical chemist, are objects of considerable importance. When the mineral is free from combined water, and other volatile matter, 20 grains of it are sufficient for an exact analysis, provided its constituents be substances with whose

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* The reader will find some good observations on the method of detecting acids by Smithson, in the *Annals of Philosophy* (second series), v. 385. And in Berzelius on the Blowpipe, p. 125.

properties we are already familiar. When the water or volatile matter amounts to between ten and twenty per cent., we should employ 25 or 30 grains of it. When we employ 50 or 100 grains, the process is more tedious, and the results scarcely so much to be depended on. Mr. Smithson, who was a very accurate experimenter, never employed more than 10 grains, and he assured me that when he took a greater quantity he ould not rely so much upon his results. Berzelius, the ccuracy of whose analyses is sufficiently known to chemists, mploys from 1 to 2 grammes; that is, from 15·4 to 30·8 rains.

I have already explained the method of separating the silica, which is so general a constituent of stony minerals. After the filter containing it has been washed till the water ceases to be ffected by nitrate of silver, it is to be placed between two folds of blotting paper, and dried in a temperature of at least 212°. As much of the dry silica as possible is taken off the filter, put into a platinum crucible, ignited, and weighed. The filter, with what silica may still adhere to it, is burnt in a platinum crucible, and the weight of the residual ashes ascertained.

A given weight of the filtering paper employed must have been previously burned, and the weight of the ashes left scertained. Thus, 40 grains of the filtering paper which I mploy at present, when burnt leave 0·165 grains of ashes. he weight of the filter employed having been determined efore we began to use it, the ashes which it would leave are nown by an easy calculation, and deducting this weight from he ashes left when the filter was burnt, we have the weight f the silica which adhered to it. This portion being added to he former quantity of silica, weighed separately, we have bviously the whole silica contained in the mineral.

Some attention is necessary in weighing a filter, because it s apt to vary something in weight according to the moisture or dryness of the atmosphere. I employ a glass tube of such a size as to contain the filter easily. One end is shut with a slip of cork, the surface of which is covered with sealing-wax; to the other end a cork, the outer end of which is also coated with sealing-wax, is fitted. This tube, with its corks, is weighed, and the weight marked upon it with a diamond. The filter to be weighed is rendered as dry as possible, by heating it before the fire, and when still warm it is enclosed in the tube and weighed, deducting from the whole weight that of the tube in which the filter is enclosed.

In some cases, as in weighing sulphur, iodine and selenium, which cannot be ignited, it is requisite to cut two filters of the same size, from the same sheet of filtering paper. These two filters are balanced against each other, and made of equal weights, by cutting small portions from the one which of the two is heaviest. When the sulphur, &c., contained on the filter is to be determined, the two filters are dried in a gentle heat, and then put into opposite scales, the additional weight necessary to counterpoise the filter containing the sulphur gives us the weight of the filter. When this method is pursued with the requisite care, it gives results very near the truth.

It is proper to wash the filters before using them, by steeping them for some time in water, acidulated by nitric or muriatic acid. Our filtering paper made in Great Britain generally contains a little lime, which is removed by these acids. I think it likely that this lime is introduced by the chloride of lime employed in bleaching the rags, of which the paper is made. The quantity is very small, but in general quite sensible.

After the silica has been separated, its purity must always be tested by the rules already laid down.

It remains now to separate the substances held in solution by the muriatic acid. As the processes necessarily vary according to the substances to be separated, and as a general method applicable to all would be too complicated for use, the best way of communicating the requisite information seems to be to give different examples of the analyses of minerals differently constituted.

I. *Minerals soluble at once in Muriatic Acid.*

There are a considerable number of minerals which, when reduced to powder, and digested in muriatic acid, undergo decomposition. In many the silica exists in such quantity that when the acid is concentrated, the whole is speedily converted into a jelly. The following minerals are decomposed and gelatinize with muriatic acid:—

1. Natrolite,
2. Mesolite,
3. Scolezite,
4. Lomonite,
5. Chabazite,
6. Levyine,

7. Comptonite,
8. Analcime,
9. Potash harmatome,
10. Apophyllite,
11. Leucite,
12. Elœolite,
13. Sodalite,
14. Hauyne,
15. Cronstedtite,
16. Ilvaite,
17. Gehlenite,
18. Scapolite or Meionite,
19. Table spar,
20. Nepheline,
21. Gadolinite,
22. Allophane,
23. Helvine,
24. Datholite,
25. Botryolite,
26. Lazulite,
27. Eudyalite,
28. Orthite,
29. Silicate of zinc,
30. Dioptase,
31. Meerschaum.

The following minerals are decomposed by muriatic acid, do not gelatinize with it:—

32. Stilbite,
33. Heulandite,
34. Anorthite,
35. Silicate of copper,
36. Sphene,
37. Pyrosmalite,
38. Cerite,
39. Allanite,
40. Pitchblende, or pitch-ore.

Most of these minerals, though not the whole of them, stand the action of acids, after having been ignited. Pro-ly other minerals may exist besides those above named, ch are decomposed by muriatic acid, but the preceding are e that have been tried with sufficient accuracy.

To the above list might have been added all the carbonates, the action of muriatic acid upon them must be so obvious very person, that I thought it unnecessary to include them he list.

Example I.

Analysis of Carbonate of Strontian, from Strontian.

The method of determining the quantity of carbonic acid in ineral is the following:—Procure a small Wolfe's bottle, h two mouths; one of these mouths has a ground crystal pper fitted to it; into the other a bent glass tube filled with gments of chloride of calcium is luted. Put into the bottle requisite quantity of nitric acid, sufficiently diluted with ter to act as a good solvent of the carbonate; then balance bottle, with all its appendages, and note down the weight. ke out the glass stopper, and introduce as speedily as possi-100 grains of the carbonate to be analyzed, not in powder, but in fragments. Replace the stopper, and allow the bottle to remain till the whole carbonate has dissolved, and till the carbonic acid has had time to make its escape from the bottle; for this purpose I generally allow an interval of twenty-four hours. Now weigh the bottle again, putting into the opposite scale not only the original counterpoise, but also the weight of the carbonate employed. The amount of weight necessary to balance the bottle again will represent the weight of the carbonic acid that has made its escape. If the carbonate of strontian were perfectly pure, the loss of weight would be 29·73 grains from the 100, and it usually approaches that number pretty nearly.

Evaporate the solution of strontian till the salt crystallizes, and till all the excess of acid is driven off; then re-dissolve in water. Almost always a little black powder remains, consisting of earthy matter, which I suppose to have been mechanically mixed with the carbonate, for it cannot be observed before the solution. Its weight never exceeds, in well-selected specimens, 0·2 or 0·3 grain.

The crystals of nitrate of strontian obtained are usually tinged slightly yellow, and when the solution of them is mixed with caustic ammonia red flocks separate, consisting of peroxide of iron, sometimes though very rarely slightly mixed with alumina. These flocks may be collected in a weighed filter, and the weight determined by burning the filter in the way formerly described.

The solution thus freed from iron is crystallized again, and the crystals are exposed in a platinum crucible to a heat sufficient to drive off and decompose the nitrate of ammonia, but not to injure the nitrate of strontian, and the quantity of nitrate of strontian in this anhydrous state is determined. It is then digested in absolute alcohol, which dissolves any nitrate of lime that may be present, but leaves untouched the nitrate of strontian. By weighing the residual nitrate of strontian we determine the loss of weight, and consequently the quantity of nitrate of lime dissolved. By evaporating the alcoholic solution we get the nitrate of lime, which deliquesces when exposed to the air. The nitrate of strontian indicates the quantity of strontian, as it is a compound of

Nitric acid	6·75
Strontian	6·5
	13·25

ence $\frac{6\cdot5}{132\cdot5}$, or 0·49 of the nitrate of strontian is the weight f the strontian.

In general, the carbonate of lime in the green carbonate om Strontian amounts to about 6¼ per cent. That in the rown carbonate is greater.

Example II.

Analysis of Scolezite.

Scolezite is a compound of water, silica, alumina, and lime. he method of analysis is abundantly simple.

1. Expose 25 grains of it to a red heat in a covered plati- um crucible, it assumes the appearance of porcelain, and ses at an average about 3·375 of water, making about 13·5 er cent.

2. 25 grains of the mineral are reduced to powder, and igested with muriatic acid in a platinum basin. In a few inutes the mineral dissolves, and very speedily assumes the rm of a jelly. Evaporate to dryness by a gentle heat, king care with a platinum spoon to scrape the matter from he bottom, that it may not be exposed to a decomposing eat. When all smell of muriatic acid is gone, pour upon it ater acidulated with muriatic acid, and allow it to digest pon the sand-bath for half an hour. Then throw the whole pon a filter previously weighed. The silica is retained by e filter. It must be washed in the way already described, nd when dry ignited in a platinum crucible and weighed. Vhat remains attached to the filter is determined by burning e filter in the way formerly explained. The amount of the nited silica is about 11·625, or 46·5 per cent.

The silica if pure ought to be perfectly white, and it ought melt with effervescence with carbonate of soda into a trans- rent colourless glass.

3. The liquid freed from silica, together with all the wash- gs of the silica, is to be concentrated by evaporation till it reduced to about ten cubic inches. It is then to be nearly utralized by carbonate of ammonia, stirring the whole well ter each addition, in order to drive off the carbonic acid. to the liquid thus nearly, but not quite, neutralized, pour ustic ammonia in slight excess, or till the liquid smells stinctly of ammonia. The alumina and oxide of iron hould any be present) are thrown down, while the lime

remains in solution. Separate the alumina upon a weighed filter, and wash it carefully with distilled water till every thing soluble is carried off. This is known to be the case when the liquid which passes through the filter is not affected by nitrate of silver. Then dry the filter containing the alumina, take off as much of the alumina as possible, heat it to redness, and weigh it. By burning the filter the quantity left on the paper is determined, and it must be added to the quantity ignited and weighed by itself. The weight of the alumina should be about 6·425, or 25·7 per cent.

4. To determine whether it be pure alumina, put that portion which had been ignited into a flask, and boil it with muriatic acid. The whole will dissolve except a few flocks of silica, the quantity of which will be the smaller, the more care was taken to dry the original solution before the silica was removed. In general its weight does not amount to 0·1 grain, and sometimes it is not more than 0·02, or 0·01 grain.

The muriatic solution is evaporated nearly, but not quite to dryness, to get rid of the excess of muriatic acid. It is then mixed with a considerable excess of caustic potash, or soda, till the precipitate which at first appears, be re-dissolved. If the alumina be pure the whole will re-dissolve in the caustic alkaline ley. In general a mere trace of oxide of iron remains, too little to admit of being weighed. But should the scolezite be impure the quantity of iron may be greater. Should it amount to an appreciable quantity, let it be collected on a balanced filter, washed and dried, and its weight determined by burning the filter. I never saw a specimen of scolezite in which the peroxide of iron from 25 grains of the mineral, amounted to so much as 0·01 grain.

Should any doubt be entertained whether the alumina be really alumina, or whether it may not be rather glucina, take a small particle of it, moisten it with solution of nitrate of cobalt, and expose it to a red heat before the blowpipe. If the substance be alumina it will assume a deep and fine blue colour, but this will not be the case if it was glucina.

5. The ammoniacal liquid from which the alumina had been separated is to be saturated with muriatic acid, and concentrated on the sand-bath to ten cubic inches. While still hot, it is to be mixed with oxalate of ammonia till all the lime is thrown down. The oxalate of lime is collected on a weighed filter, and washed till the liquid which passes through ceases to be affected by nitrate of silver. It is then dried, and as much

of the oxalate of lime as possible is put into a platinum crucible, and exposed to a red heat. The oxalic acid is decomposed, and the lime converted into carbonate. Mixed with this carbonate of lime there is a little charry matter which renders the colour grey. But if the heat has been raised to ignition, this charcoal just compensates for a little carbonic acid driven off, so that the whole of it may be estimated as carbonate of lime. What remains on the filter is determined by burning the filter, and from the weight of its ashes deducting that of the weight of the ashes of the filter supposed clean. From the whole carbonate of lime obtained, it is easy to deduce the lime. For carbonate of lime is composed of

Carbonic acid, . .	2·75
Lime, ...	3·5
	6·25

Let the weight of the carbonate of lime be a, the lime which it contains is $\frac{3{\cdot}5a}{6{\cdot}25}$, or $0{\cdot}56a$. It will be found on an average to amount to 3·55 grains.

6. The liquid from which the lime was precipitated may be tested for magnesia. But as scolezite contains none of that alkaline earth, none of course would be found.

Having finished the analysis, the next step is to collect all the constituents found together, and observe whether their weight amounts to as much as that of the mineral analyzed. In the present case we have

Water, . . .	3·375
Silica, . . .	11·625
Alumina, . .	6·425
Lime, . . .	3·550
	24·975

The quantity of mineral employed was 25 grains, and the weight of the constituents obtained 24·975 grains. So that the two numbers agree as nearly as can be expected in such an analysis. Had the loss amounted to 1 or 2 grains, there would be a presumption that the mineral contained an alkali, which would require to be sought for by the methods indicated in the next example.

EXAMPLE III.

Analysis of Natrolite.

The constituents of natrolite are water, silica, alumina, soda, and sometimes a little oxide of iron. The method of proceeding is almost the same as in the last example.

1. The water, the silica, the alumina, and the oxide of iron, are separated precisely as in the case of scolezite.

2. The liquid remaining after the separation of the alumina may be tested for lime and magnesia, but none will be found.

Let it be evaporated to dryness, and the residual salt being put into a platinum crucible, let it be heated almost to ignition till all the ammoniacal salts are driven off. Care should be taken not to fuse the matter in the crucible, because when that is the case a portion is apt to be driven out of the crucible and lost. What remains (if the processes have been conducted with the requisite care) is common salt. Let it be weighed and then dissolved in a little water. Into the concentrated solution let fall a few drops of an alcoholic solution of chloride of platinum. No precipitate will fall, showing that the alkali in the salt is soda. Every seven and a half grains of common salt are equivalent to 4 grains of soda. Let the weight of common salt obtained be a, the soda is equal to $\frac{4a}{7\cdot5}$, or $0\cdot533a$. If we have employed 25 grains of natrolite in the analysis, we shall obtain at an average about 7·855 grains of common salt, equivalent to 4·19 grains of soda, or 16·76 per cent.

EXAMPLE IV.

Analysis of Ilvaite.

This mineral contains five ingredients; namely, silica, alumina, protoxide of iron, protoxide of manganese, and water.

1. When ilvaite is heated to incipient ignition, it gives out water. The mineral by this treatment assumes a shining black colour, and becomes attracted by the magnet, which is not the case with it before this roasting. 25 grains of ilvaite give out at a medium, about 0·317 grain of water, which makes the water in this mineral to amount to 1·268 per cent.

2. When 25 grains of ilvaite, in the state of fine powder, are digested in muriatic acid, a solution is soon effected, and the whole is speedily converted into a jelly. The solution is

porated to dryness, and the residue digested in water aci-
ated with muriatic acid, and thrown on a weighed filter in
er to separate the silica. It is washed, dried, ignited, and
ghed, exactly in the way already described. The quan-
of silica from 25 grains of ilvaite, is at an average about
19 grains, which is equivalent to 29·276 per cent.

3. To peroxidize the iron which constitutes so great a pro-
tion of ilvaite, a little nitric acid is added, and the liquid is
ested for some time. The peroxide of iron, together with
alumina, are then precipitated by dropping bicarbonate of
a into the cold liquid. The precipitate, while still moist,
ligested with caustic potash ley to dissolve off the alumina.
e peroxide of iron is then collected on the filter, washed,
ed, ignited, and weighed. From 25 grains of ilvaite, we
ain 14·595 grains, equivalent to 13·1355 grains protoxide,
52·542 per cent. For 10 parts of peroxide of iron are
ivalent to 9 parts of protoxide.

4. Sal ammoniac being poured into the potash ley which
l been digested over the peroxide of iron, a quantity of
mina falls, which after being washed, dried, and ignited,
ighs at an average 0·1535 grain, or 0·614 per cent.

5. The liquid (No. 3) from which the iron had been pre-
itated, still retains lime and oxide of manganese in solu-
n. It is raised to a boiling temperature, and completely
cipitated by carbonate of soda. The precipitate is washed
l dried, and exposed in an open vessel to a temperature
ficiently high to expel the carbonic acid from the lime, and
vert the manganese into black oxide. From this mixture
ite nitric acid dissolved out almost all the lime, leaving the
de of manganese, still contaminated with a little lime.
is residue is again exposed to a red heat, and afterwards
gested in dilute nitric acid, which dissolves out all the lime,
d leaves the manganese in the state of sesquioxide, every
grains of which are equivalent to 4·5 grains of protoxide of
nganese. The average quantity of sesquioxide of man-
nese from 25 grains of ilvaite, is 0·441, equivalent to 0·397
ain of protoxide, which amounts to 1·587 per cent.

6. The lime is precipitated from the nitric acid solution by
utralizing it with carbonate of soda, raising it to the boiling
nperature, and throwing it down in the state of carbonate
lime. The average weight of carbonate of lime from 25
ains of ilvaite, is 6·15 grains, equivalent to 3·444 grains of
ie, which amounts to 13·776 per cent.

Having thus finished the analysis, we must collect all the ingredients, and see whether their weights correspond with the weight of the mineral analyzed. We have,

Water, . . .	0·317
Silica, . . .	7·319
Protoxide of iron, .	13·1355
Alumina, . . .	0·1535
Protoxide of manganese,	0·3970
Lime, . . .	3·4440
	24·766

The loss being only 0·234, or less than one per cent., we conclude that the analysis has been rightly conducted, and none of the constituents overlooked.

Example V.

Analysis of Eudyalite.

The constituents of this mineral, which was first analyzed by Stromeyer, are silica, zirconia, lime, soda, peroxide of iron, protoxide of manganese, muriatic acid, and water.

1. The quantity of water is determined in the usual way by ignition in a platinum crucible. 25 grains of the mineral lose, at an average, 0·45 grain, or about 1·8 per cent.

2. Being reduced to a fine powder, it is to be digested in muriatic acid. It speedily gelatinizes. Being evaporated to dryness, and the residue digested in water acidulated with muriatic acid, the silica is to be separated in the way already explained. 25 grains of the mineral yield, at an average, 13·331 grains of silica, or 53·325 per cent.

2. The liquid thus freed from silica, is neutralized as exactly as possible with ammonia, and then mixed with succinate or benzoate of ammonia. The precipitate is separated, washed, dried, and ignited, in a covered crucible. It is then fully calcined in an open vessel. In this state it is a mixture of peroxide of iron and zirconia. It is weighed and then digested in muriatic acid. The peroxide of iron is dissolved, and the zirconia left behind is washed and dried. The peroxide of iron from 25 grains of eudyalite, weighs at an average 1·69 grains, or 6·754 per cent. The zirconia remaining behind, weighs at an average 2·775 grains, or 11·1 per cent.

3. The liquid thus deprived of its iron and zirconia, is treated with sulpho-hydrate of ammonia to throw down the

manganese. The precipitate thus obtained, is dissolved in nitric acid, and the manganese again precipitated by means of carbonate of soda. The precipitate after being washed, dried, and ignited, is red oxide of manganese, every 4·833 grains of which is equivalent to 4·5 grains of protoxide of manganese, or the protoxide is equal to 0·931 of the red oxide obtained. The quantity of protoxide from 25 grains of the mineral, amounts at an average to 0·515 grain, or 2·062 per cent.

4. The liquid thus freed from manganese, is mixed with oxalate of ammonia to throw down the lime. The oxalate of lime is treated as already explained, aud the weight of lime deduced from it by the rules formerly laid down. 25 grains of eudyalite yield at an average 2·446 grains of lime, or 9·785 per cent.

5. The residual liquid is now evaporated to dryness, and e dry residue exposed to heat in a platinum crucible to ive off the ammoniacal salts. The saline matter remaining dissolved in water. A little platinum derived from the ucible sometimes remains behind. The solution being eated with oxalate of ammonia, a little oxalate of lime is parated, the lime of which is included in the preceding stimate. When the carbonate of lime obtained from this xalate is dissolved in nitric acid, a few flocks of red oxide of manganese generally remain undissolved.

6. The saline solution is again evaporated to dryness, and the residual salt ignited. It is now weighed and then dissolved in water. A very minute quantity of carbonate of lime may remain behind. The solution being sufficiently concentrated, crystallizes in cubes, which have all the properties of common salt. From the weight of this common salt, that of the soda contained in the mineral may be deduced. It amounts to 3·455 grains from 25 of eudyalite, or to 13·822 per cent.

7. To determine the amount of muriatic acid which eudyalite contains, a quantity of the mineral in powder may be digested with nitric acid, in a close vessel till it gelatinizes. The silica is then separated by the filter, and the nitric acid liquid is treated with nitrate of silver. A precipitate of chloride of silver falls, which is separated by the filter, washed, dried, and fused upon a piece of glass. From the weight of this chloride, it is easy to deduce the weight of muriatic acid in the mineral. For 18·25 grains of chloride of silver are

equivalent to 4·625 grains of muriatic acid. Let the weight of chloride of silver be a, the muriatic acid $= \frac{4·625a}{18·25}$ or $= 0·253a$. The muriatic acid from 25 grains of eudyalite, amounted to 0·258 grain, equivalent to 1·034 per cent.

The constituents of eudyalite obtained by the preceding analysis, being collected, amount to

Water,	0·450
Silica,	13·331
Peroxide of iron,	1·688
Zirconia,	2·775
Protoxide of manganese,	0·515
Lime,	2·446
Soda,	3·455
Muriatic acid,	0·258
	24·918

Here the loss does not exceed 0·328 per cent., a quantity so small, that we may conclude that no constituent has been overlooked.

EXAMPLE VI.

Analysis of Orthite.

This mineral contains, like the preceding, no fewer than six different constituents; namely, lime, alumina, yttria, protoxide of iron, protoxide of manganese, and oxide of cerium.

1. The mineral being reduced to powder, 25 grains of it are to be dissolved in aqua regia, and the silica separated and estimated by the methods already described.

2. The acid solution, together with the washings of the silica, are concentrated to the bulk of about 10 cubic inches. Caustic ammonia being added in slight excess, every thing is thrown down except the lime, which still remains in solution. The liquid being poured into a cylindrical glass vessel, is covered with a glass plate, and left at rest to allow the precipitate to sink to the bottom, while at the same time, the carbonic acid of the atmosphere is prevented from having access to the ammonia, which would occasion a precipitate of carbonate of lime. The clear liquid is then drawn off with a sucker, and the sediment being diluted with hot water, is thrown upon a balanced filter. The filter and its contents are washed with distilled boiling hot water, in the way already described, till the precipitate is perfectly clean.

3. The water thus employed to wash the filter, together ith the portion drawn off with a sucker, is concentrated to out 10 cubic inches, neutralized with muriatic acid, and en precipitated while hot with oxalate of ammonia. The xalate of lime thrown down is collected on a weighed filter, ashed and ignited. It indicates the quantity of carbonate of me, from which the pure lime is to be deduced by the method lready explained.

4. The precipitate collected on the filter (in No. 2) is put nto a flask while still moist, and boiled for a couple of hours n a caustic ley of potash or soda. By this process the alumina is dissolved, while the other constituents remain unacted pon.

As it is impossible to take the whole precipitate off the lter, we must proceed as follows:—We remove as much as e can conveniently, without injuring the texture of the filter. Ve then put the filter into a porcelain dish, and pour over it ater acidulated with muriatic acid. If we leave the filter r some time in this liquid, the whole remainder of the pre- pitate will be dissolved. The solution being neutralized, poured into the flask containing the potash ley and the rest the precipitate. The filter is to be washed with a little dis- led water, which is poured also into the ley. Care must be ken not to injure the texture of the filter, nor to convert y of it into pulp. Should such pulp appear, it is best to et rid of it by passing the muriatic solution through a filter, king care to concentrate it sufficiently before pouring it into e flask.

To know whether the muriatic liquor (supposing we do not turate it) may not saturate too much of the potash, let a rop of muriatic acid be let fall into the ley. A precipitate ill at first appear, but it will dissolve again upon the least itation of the liquid, if the potash present be in sufficient antity. Should this precipitate not dissolve again, it is a gn that the quantity of potash employed is too small. In at case, the portion of precipitate not dissolved in the ley, ust be again digested in a new portion of potash ley.

5. The alkaline ley having thus taken up the alumina, is awn off, and the undissolved matter washed clean upon a ter, taking care to add the washings to the potash ley, and concentrate till the bulk be reduced to a convenient quan- y for use. Then sal ammoniac being added in sufficient antity to saturate the alkali with muriatic acid, the alumina

is precipitated. It is collected on a double filter, washed with hot water, dried, ignited, and weighed.

The alumina obtained in this way is almost always mixed with a little silica. To separate this portion, the alumina is boiled in a flask with muriatic acid till every thing soluble be taken up; the white residue remaining is the silica, which must be separated, washed, ignited, and weighed, and its weight added to that of the silica previously obtained.

When the alumina constitutes the greatest part of the matter thrown down by the ammonia, the best method of proceeding is this:—After washing the precipitate, dry it and expose it to a red heat.* Let it then be dissolved by digestion in muriatic acid; the silica remains undissolved. To the solution add a sufficient quantity of caustic potash or soda; the alumina will be retained in solution, but the other constituents will be thrown down. Let the undissolved portion be collected, washed, dried, and ignited. Its weight deducted from that of the original quantity of ignited precipitate, gives the true quantity of alumina which the mineral contains. This mode of proceeding is advantageous, because alumina is bulky and difficult to wash, and consequently occupies a good deal of time; we save a troublesome washing, and are thus enabled to finish the analysis in a shorter time. But we must be careful to ascertain, before having recourse to it, that no other constituent be present besides alumina, which is soluble in caustic potash ley.

6. The matter not dissolved by the potash still remains to be examined. It is a mixture of yttria, oxide of cerium, oxide of iron, and oxide of manganese. It is dissolved in muriatic acid, and into the solution a crust of sulphate of potash is put, of such a size that it rises up higher than the surface of the liquid, and it is left in this state for twenty-four hours, to give the liquid time to be saturated with the salt. As oxide of cerium has the property of forming a compound salt with sulphate of potash, which is insoluble in a saturated solution of sulphate of potash (no matter whether any uncombined acid be present or not), it will be all precipitated in the

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* The portion that adheres to the filter is determined by burning the filter, and allowance must be made for that portion when the precipitate is analyzed. Suppose the portion of the precipitate ignited to be 10 grains, and the portion which remains in the filter to weigh 0·2 grain. It is obvious that we must augment the weight of each constituent found, by a fiftieth part, to allow for the portion lost on the filter.

state of this compound salt. The clear liquid is drawn off, and the white precipitate is washed with water saturated with sulphate of potash, till it is clean. It is then dissolved in water, and the oxide of cerium precipitated by caustic potash or soda. If we precipitate it by ammonia, the oxide of cerium still retains sulphuric acid. The precipitate is collected on a filter, washed, dried, and ignited. It is now peroxide of cerium.

The atom of peroxide of cerium weighs 7, and that of protoxide 6·5. Let the weight of peroxide obtained be a, the weight of protoxide of cerium corresponding is $\frac{6\cdot5\,a}{7}$, or $0\cdot9286a$.

7. The liquid thus freed from oxide of cerium is rendered as neutral as possible by ammonia, and then benzoate of ammonia is added in sufficient quantity to throw down the whole of the peroxide of iron which it contains. The precipitate after being washed, dried, and ignited in an open crucible is peroxide of iron, the weight of which must be determined.

If we dry the benzoate of iron in a temperature not under 212°, it is anhydrous, and when weighed in that state one-fourth of its weight indicates the quantity of peroxide of iron which it contains.

It is necessary, in order to throw down iron by benzoate of ammonia, that the metal should be in the state of peroxide. This is accomplished by adding a few drops of nitric acid to the liquid before it is neutralized by ammonia, and digesting it for some time on the sand-bath.

If the liquid be not completely neutralized by ammonia, the benzoate of ammonia will still throw down the peroxide of iron. But we cannot wash the precipitate with pure water, because that liquid would dissolve a little of it, and acquire a red colour. In such a case we must wash the precipitate with water, holding salammoniac in solution, because the presence of that salt prevents the water from dissolving benzoate of iron, even when there is a slight excess of acid present.

The iron in the mineral was in the state of protoxide, but by the above process we obtained it in the state of peroxide. Now the atom of protoxide of iron is 4·5, and that of peroxide 5. Hence the protoxide amounts to nine-tenths of the corresponding quantity of peroxide.

If succinate of ammonia be employed instead of benzoate, the process is the same. In this country the high price of succinic acid precludes its employment in chemical analyses.

8. Nothing now remained in the liquid but yttria and protoxide of manganese. Ammonia being added, the yttria is precipitated, while the oxide of manganese remains in solution in the state of a double ammoniacal salt. The yttria being collected on a filter, washed, dried, and ignited, the amount of its weight is determined.

9. To the liquid now freed from every thing except oxide of manganese, an excess of carbonate of soda is to be added, and the whole evaporated to dryness, to drive off the ammonia. The dry residue being digested in water, every thing dissolves except the carbonate of manganese. It is washed, dried, moistened with nitric acid, and heated to incipient ignition. It is now sesquioxide of manganese, the atom of which weighs 5, while that of protoxide weighs 4·5. Hence the protoxide constitutes nine-tenths of the sesquioxide obtained.

When oxide of manganese is exposed to a strong red heat, its colour becomes reddish brown. In this state it is a compound of one atom protoxide and two atoms sesquioxide of manganese. Its atom weighs 4·833. In this case to find the amount of protoxide from that of the red oxide, we say $4{\cdot}833 : 4{\cdot}5 :: a$ (= weight of red oxide) $: \frac{4{\cdot}5a}{4{\cdot}833}$, or $0{\cdot}931a$.

Another mode of separating yttria from oxide of manganese is to add carbonate of soda to the liquid containing both, and then to evaporate the whole to dryness. When the dry residue is washed with water, a mixture of yttria and carbonate of manganese remains. If we digest this mixture while still moist, in a large quantity of carbonate of ammonia, the yttria will be dissolved, while the oxide of manganese will be left behind. By boiling the ammoniacal liquid we throw down the yttria, which is collected, washed and determined as before explained. The oxide of manganese is treated exactly as has just been described.

The constituents thus obtained are now to be collected, and it will be found that they nearly amount to the weight of the mineral analyzed. Hence it may be inferred that no constituent has been overlooked.

II. *Minerals requiring to be heated with Carbonate of Soda.*

The preceding examples are sufficient to enable the young analyst to analyze those minerals which dissolve in muriatic acid. The remaining stony bodies, in order to become soluble in muriatic acid, require to be reduced to a fine powder, to be intimately mixed with twice or thrice their weight of anhydrous carbonate of soda, and to be ignited for an hour in a platinum crucible. The following table exhibits the names of some of the most remarkable minerals that require this treatment:—

1. Felspar.
2. Albite,
3. Petalite,
4. Spodumene,
5. Labradorite,
6. Andaluzite,
7. Barytes harmotome,
8. Chrysolite,
9. Prehnite,
10. Mica,
11. Lepidolite,
12. Talc,
13. Chlorite,
14. Pinite,
15. Achmite,
16. Amphibole,
17. Pyroxene,
18. Anthophyllite,
19. Diallage,
20. Epidote,
21. Idocrase,
22. Garnet,
23. Dichroite,
24. Staurolite,
25. Emerald,
26. Euclase,
27. Tourmalin,
28. Axinite,
29. Topaz,
30. Chondrodite,
31. Picrosmine,
32. Carpholite,
33. Steatite,
34. Serpentine,
35. Nacrite,
36. Obsidian,
37. Pitchstone,
38. Bytownite,
39. Plinthite,
40. Schiller spar,
41. Hyperstene,
42. Retinalite,
43. Bucholzite,
44. Cyanite,
45. Zoisite,
46. Hydrolite.

I shall give examples of the mode of analyzing these minerals, according to their constituents.

EXAMPLE I.

Analysis of Albite.

The constituents of this mineral are silica, alumina, and soda, with a very little lime, and peroxide of iron. It differs from felspar merely in containing soda instead of potash, which is the constituent in felspar.

This mineral containing an alkali, and being insoluble in muriatic acid, we may adopt the following process for ascertaining its constituents:—

1. Let 25 grains of it in the state of fine powder be intimately mixed with four times its weight of nitrate of barytes, in a platinum crucible, and the mixture exposed for two hours to a strong red heat. The fused mass is to be dissolved in muriatic acid, and the silica separated in the way already described. It will amount, at an average, to 17·669 grains.

2. The remaining liquid freed from silica is to be concentrated to a manageable quantity, and mixed with sulphate of ammonia, to throw down the barytes. The sulphate of barytes must be separated by the filter, and the liquid, reduced to a manageable quantity, is to be heated to the boiling point, and mixed with carbonate of ammonia in excess, which will throw down the alumina, together with the lime and oxide of iron.

3. The liquid thus freed from every thing except the alkali is to be evaporated to dryness, and the residual matter heated to drive off the ammoniacal salts. A small quantity of saline matter remains, which after fusion is to be dissolved in water and evaporated. It will yield cubic crystals to the very last drop, having all the properties of common salt, and will not be precipitated either by an alcoholic solution of chloride of platinum, or by tartaric acid. It weighs at an average 4·245 grains, indicating 2·264 grains of soda, or 9·056 per cent.

From the method employed to throw down the barytes it may happen that the common salt may be mixed with a little sulphate of soda. To determine this point the common salt obtained must be dissolved in water, and the solution tested by chloride of barium. The precipitate, if any fall, must be collected, washed, ignited, and weighed. Let it weigh a, the sulphuric acid in it will be $\frac{5a}{14{\cdot}5}$, or $\frac{a}{2{\cdot}9}$, or $0{\cdot}3448a$. The soda united to this sulphuric acid will be $\frac{4a}{14{\cdot}5}$, or $0{\cdot}2758a$. This gives us the weight of the sulphate of soda present $= 0{\cdot}6206a$. This quantity must be subtracted from the common salt. We must determine the soda equivalent to the remainder, and adding to this the soda in the sulphate, we obtain the whole soda in the mineral.

3. The precipitated alumina, with the lime and oxide of iron, are to be dissolved in a little muriatic acid, and the solution neutralized and mixed with caustic ammonia in slight

excess. The alumina and oxide of iron will be precipitated, while the lime remains in solution.

4. Let the liquid containing the lime be precipitated hot with oxalate of ammonia, and let the precipitate be collected, washed, dried, and ignited. It is carbonate of lime, weighing at an average 0·105 grain, indicating 0·059 grain of lime, or 0·235 per cent.

4. Let the precipitated alumina, &c., while still moist, be digested in caustic potash ley; the whole will dissolve, except a minute quantity of reddish-brown matter. This matter being tested will be found to be peroxide of iron, with a slight trace of protoxide of manganese; the weight is only about 0·028 grain, or 0·111 per cent. To analyze with accuracy so minute a quantity of matter is impossible, but the quantity of manganese in it may barely be made appreciable by the blowpipe.

5. The potash ley may now be mixed with sal ammoniac. The alumina will be precipitated. Let it be washed, dried, gnited, and weighed: its weight at an average amounts to 1·95 grains, or 19·801 per cent. Being digested in muriatic cid, it generally leaves a minute quantity of silica, which is o be estimated and added to the weight of the silica originally ound, while its amount is to be subtracted from the alumina.

Having finished the analysis, we collect as usual all the constituents together, that we may see their amount.

Silica, . . .	17·669
Soda, ...	2·264
Alumina, . . .	4·950
Lime, . . .	0·059
Peroxide of iron, .	0·028
	24·970

As the quantity nearly coincides with the weight of the mineral employed, we may consider it as certain that we have not omitted any of the constituents.

EXAMPLE II.

Analysis of Garnet.

There is a variety of minerals at present confounded together under the name of garnet; but the kind of garnet which I employ here as an example is the dark red variety, having a specific gravity of 4·236. Its constituents are silica, alumina, protoxide of iron, and protoxide of manganese.

1. 25 grains of this garnet, reduced to a fine powder, are to be mixed with thrice their weight of anhydrous carbonate of soda, and exposed to a red heat for an hour and a half in a platinum crucible. The matter, if melted, will have assumed a dark green colour. It must be dissolved in muriatic acid, and the solution evaporated to dryness. The dry residue being digested for an hour in water acidulated with muriatic acid, the whole is thrown on a weighed filter, and the silica which remains upon the filter must be washed, dried, ignited, and weighed. It amounts, on an average, to 9·965 grains, or 39·86 per cent.

2. The liquid from which the silica had been separated is to be concentrated to a manageable quantity, and then mixed with caustic ammonia in slight excess. The mixture may be allowed to remain for half an hour in a covered vessel to give time to the precipitate to subside. It is then to be collected on a filter, washed, dried, ignited, and weighed. Being again dissolved in muriatic acid, a little silica will remain behind, which is to be separated and weighed.

3. The solution is now to be mixed with a great excess of caustic soda, and boiled for some time that all the alumina may be dissolved. The undissolved portion is then separated by the filter, washed, dried, ignited, and weighed. Its weight, together with that of the silica (in No. 2.) being subtracted from the original weight of the ignited precipitate, will give the weight of the alumina dissolved by the caustic soda ley. It amounts at an average to 4·915 grains, or 19·66 per cent.

4. The oxide of iron, &c., (of No. 3.) is to be dissolved in a boiling heat in aqua regia. A little silica remains behind, which must be separated, washed, dried, ignited, and weighed. Its weight is to be added to that of the silica obtained in No. 1.

5. The solution being neutralized as nearly as possible with caustic ammonia, the peroxide of iron is to be thrown down by benzoate of ammonia. The precipitate, washed with cold water, and afterwards with water containing a little ammonia, is to be heated to redness and weighed. The weight at an average amounts to 11·02 grains, equivalent to 9·92 grains of protoxide of iron, or 39·68 per cent.

6. The liquid thus freed from iron is to be mixed with carbonate of soda in excess, and evaporated to dryness. The

residue being digested in water to dissolve the saline constituents, a quantity of white matter remains, which becomes brown by ignition, and is the red oxide of manganese, together with a very minute portion of silica, and a trace of lime. Its weight at an average amounts to 0·456 grain, equivalent to 0·425 grain of protoxide, or 1·7 per cent.

We now as usual collect all the constituents together.

Silica, ...	9·965
Alumina, . . .	4·915
Protoxide of iron, . .	9·920
Protoxide of manganese, .	0·425
	25·225

In this case the constituents rather surpass the original eight of the mineral. We may be satisfied, therefore, that no nstituent has been overlooked.

Example III.

Analysis of Hornblende.

The constituents of this mineral are numerous; namely, silica, agnesia, lime, protoxide of iron, alumina, protoxide of manganese, fluoric acid, and water. As it contains magnesia as a onstituent, several precautions are necessary in order to obtain hat substance in a state of purity. It has a great tendency to form double salts, and from this it happens that we are apt to get the magnesia contaminated with some foreign matter which increases its quantity beyond the truth, so that in analyzing magnesia minerals we often obtain a greater weight when we add the constituents together, than the amount of the whole mineral submitted to analysis. To put the young analyst on his guard against these mistakes, it will be requisite to enter somewhat into detail. The present example will show the general method of managing minerals which contain magnesia as a constituent.

1. The mineral reduced to a fine powder, is to be mixed with three times its weight of anhydrous carbonate of soda, and exposed for an hour to a red heat in a platinum crucible. The matter whether it has been fused or only made to cohere by the heat, is to be dissolved in muriatic acid. In general a few white flocks remain undissolved, easily distinguished by their lightness from the undecomposed powder of the mineral.

2. The muriatic acid solution is evaporated to dryness, care

being taken to make the heat equable, and to break all the little knots that may remain, that every portion of the residue may be equally dried. The dry residue is then mixed with water acidulated with muriatic acid, and allowed to digest for an hour. The whole is then thrown on a weighed filter, and the silica washed, dried, ignited, and weighed.

3. The liquid thus freed from silica, is precipitated by caustic ammonia, taking care to add as small an excess as possible, lest a portion of the alumina should be kept in solution. The precipitate is to be collected on a weighed filter washed with hot water, put while still moist into a caustic soda ley, and boiled in it for an hour in order to dissolve th alumina. Or, instead of this, we may ignite the precipitate and dissolve it in muriatic acid. A little silica will remain which is separated, washed, ignited, and weighed. The solution is mixed with an excess of potash or soda ley, boiled wit it an hour, and then what remains undissolved, is separate from the alkaline ley by the filter.

4. The alkaline liquid (of No. 3.) is saturated with muriati acid, added in such quantity, that the alumina at first thrown down is re-dissolved. It is then thrown down by carbonate of ammonia. The alumina is collected on a filter, washed with hot water, dried, ignited, and weighed. If it be dissolved in dilute sulphuric acid, a little silica usually remains behind; and if to the solution sulphate of potash or sulphate of ammonia be added, crystals of alum are gradually deposited.

5. The portion of the precipitate (of No. 3.) not dissolved by boiling it in an alkaline ley, is dissolved in muriatic acid, a little nitric acid is added, and the whole boiled a little while to peroxidize the iron. The solution is diluted with water, neutralized by caustic ammonia, and precipitated by succinate or benzoate of ammonia. The iron is thrown down in the state of peroxide, and in combination with the acid of the salt employed as a precipitant. The benzoate of iron must be collected in a filter, washed with cold water, dried, and ignited. The acid is dissipated and pure peroxide of iron remains, provided the ignition has been continued long enough in an open vessel. From the weight of peroxide of iron thus obtained that of the protoxide of iron, which is the state in which iron exists in hornblende, is easily deduced by the method already explained at full length in a preceding example.

6. The liquid thus freed from iron, may be tested by the addition of a little carbonate of ammonia, to see whether it

may not still retain a trace of alumina, which may have escaped the action of the alkaline ley. Should any precipitate appear, it must be separated, washed, dried, and ignited, and its weight added to that of the alumina already obtained. What liquid remains after these processes, may be added to the liquid No. 2., from which the alumina and iron have been thrown down by means of caustic ammonia.

7. The liquid of No. 2. contains still the lime, magnesia, and oxide of manganese. It must be heated to drive off all the excess of caustic ammonia which it contains. It is then diluted with hot water and precipitated by oxalate of ammonia. When the oxalate ceases to produce any more effect, the oxalate of lime is collected on the filter, washed, dried, and ignited. It is converted into carbonate of lime, from which the lime contained in the mineral is to be deduced in the way already explained.

For greater security, we may saturate the lime with sulphuric acid, and after igniting the sulphate of lime, determine its weight. Supposing the sulphate anhydrous, as it is rendered by ignition, every $8\frac{1}{2}$ grains of it contain 3·5 grains of lime. Let the weight of sulphate be a, the lime contained in it is $\frac{3{\cdot}5a}{8{\cdot}5}$ or $0{\cdot}412a$.

8. The liquid thus freed from lime is to be evaporated, but to prevent the precipitation of any oxalate of magnesia during the evaporation, which would happen if an excess of oxalate of ammonia had been added, a few drops of muriatic acid is added to it. The concentrated solution is mixed with carbonate of soda, added at first cautiously, till the sal ammoniac in the liquid is decomposed and its ammoniac driven off, then more carbonate of soda is added, the liquid being kept boiling hot till the magnesia is precipitated. These precautions are requisite to prevent the double magnesian salt from forming. The employment of carbonate of soda instead of carbonate of potash, has also a tendency to prevent the formation of the double salt, for soda-carbonate of magnesia does not form nearly so readily as potash-carbonate.

When the precipitated magnesia concretes together into a heavy, fine, granular powder, we may conclude that it is all precipitated and that no double salt is present. We may then collect it on the filter. But when it is bulky and light like alumina, we must not attempt to filter, but continue the boiling. To make it certain that all the magnesia is thrown down, the best way is to evaporate to dryness, taking care to stir the mixture from the bottom with a glass rod, to prevent the matter from agglutinating together. The dry residue is digested in hot water. The carbonated magnesia is now collected on a filter and washed. The process of washing is easy, not requiring more than half an hour. It is now to be dried, ignited strongly, to drive off the carbonic acid, and weighed. If we dissolve the magnesia thus obtained in muriatic acid or dilute sulphuric acid, a little silica usually remains undissolved.

9. The solution neutralized by ammonia, is mixed with a little sulphohydrate of ammonia, to throw down the oxide of manganese. The precipitated manganese is dissolved in muriatic acid, filtered, precipitated by carbonate of soda at a boiling temperature, washed, dried, ignited, and weighed. It is in the state of red oxide, every 4·833 grains of which are equivalent to 4·5 grains of protoxide of manganese.

10. The solution thus freed from manganese, is heated to drive off the sulphuretted hydrogen, saturated with sulphuric acid and evaporated to dryness. By dissolving the residual salt in water, we satisfy ourselves whether any lime has remained united to the magnesia. Should any gypsum remain, it must be separated, washed with a little water applied at intervals, dried, ignited, and weighed. The lime contained in it amounts to $\frac{3 \cdot 5}{8 \cdot 5}$ or 0·412 of the whole gypsum.

This portion of lime, together with the small quantity of silica and oxide of manganese obtained, being subtracted from the whole weight of the precipitate, the remainder gives the quantity of magnesia contained in the mineral.

It deserves attention, that the silica obtained when the precipitated magnesia is dissolved in sulphuric acid, however carefully washed, and though its weight is not greater than when the magnesia has been dissolved in muriatic acid, possesses however some peculiar properties. It is more bulky and seems composed of scales, coheres together before the blowpipe, and gives a light blue colour when heated with nitrate of cobalt. Bonsdorff, to whom we owe these observations, examined this silica with the utmost care, and could find nothing in it except a trace of lime, so small as not to be capable of being appreciated.* This singular variety of silica

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* Köng. Vet. Acad. Handl., 1821, p. 205.

always occurs whenever the magnesia from a mineral holding magnesia is dissolved in sulphuric acid.

11. To determine the quantity of water in the mineral, a given weight of it is exposed to a red heat in a platinum crucible for a quarter of an hour. A spirit lamp may be very conveniently employed for this trial. If we now expose the same portion of mineral to a white heat for half an hour, it will be found to lose an additional weight, amounting in hornblende, generally to from half a per cent. to 3 per cent.*

Example IV.

Analysis of Emerald.

The constituents of this mineral are silica, alumina, glucina, oxide of iron, and according to Vauquelin, oxide of chromium, and according to Berzelius, columbic acid.

1. 25 grains of it in the state of fine powder are well mixed with thrice their weight of carbonate of soda, and heated for an hour in a platinum crucible. Towards the end of the process I usually raise the heat sufficiently high to fuse the mixture. The fused mass is digested in dilute muriatic acid, which dissolves every thing except a few flocks of silica. The solution is gradually evaporated to dryness in a porcelain dish, and the dry residue being digested for an hour in dilute muriatic acid, the silica is collected on a filter, and its quantity determined in the way already described.

2. The liquid which has passed through the filter being concentrated to a manageable quantity, and almost neutralized with carbonate of ammonia, taking care to agitate well in order to expel the whole carbonic acid, is then precipitated by caustic ammonia.

3. The precipitate, while still moist, is put into a bottle with a crystal stopper, and a large quantity of solution of carbonate of ammonia being poured over it, the whole is well agitated, and the bottle left for twenty-four hours, agitating occasionally during the interval. The undissolved portion being allowed to subside, the clear solution is drawn off by a sucker, and an additional quantity of carbonate of ammonia being poured into the bottle, the whole is well agitated and left for twenty-four hours more, agitating

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* The reader will find an excellent set of directions for analyzing magnesian minerals, in Bonsdorff's paper on Amphibole. Köng. Vet. Acad. Handl., 1821, p. 197.

occasionally during that interval. The whole is now to be poured upon a filter, and the residue washed with solution of carbonate of ammonia till every thing soluble is removed.

4. The carbonate of ammonia solution contains the glucina. This earth is precipitated by boiling the liquid in a glass flask till the excess of ammonia is driven off. As the liquid could not be free from muriatic acid, it may be proper to add a few drops of caustic ammonia, in case the muriatic acid may have taken up any of the glucina, in order in that case to throw it down again. The precipitated glucina is collected on the filter, washed, dried, ignited, and weighed.

5. It will be proper to examine the glucina thus obtained, in order to ascertain its purity, or whether it be really glucina.

(1.) Pure glucina has a white colour, and is tasteless and insoluble in water. But it dissolves in acids, even after ignition, though not without difficulty. The saturated acid solutions of glucina have a sweet taste.

(2.) No acid occasions a precipitate when poured into a solution of a glucina salt.

(3.) When potash ley is poured into a solution of glucina, a bulky precipitate falls, which is completely dissolved in an excess of potash. If to this solution containing potash and re-dissolved glucina you add sal ammoniac, the glucina is again precipitated.

(4.) Ammonia produces in solutions of glucina a bulky precipitate, which does not re-dissolve in an excess of ammonia. The presence of sal ammoniac in this solution does not prevent the appearance of the precipitate.

(5.) Carbonate of potash throws down a bulky precipitate from solutions of glucina, which is re-dissolved by an excess of the precipitant.

Carbonate of soda, carbonate of ammonia, and the bicarbonates of these alkalies, and of potash, act precisely in the same way.

(6.) Phosphate of soda throws down a bulky precipitate from solutions of glucina.

(7.) Oxalate of ammonia occasions no precipitate.

(8.) When potash is added to a solution of glucina containing an excess of sulphuric acid, no crystals of alum are produced.

(9.) Prussiate of potash occasions no precipitate.

(10.) Sulphohydrate of ammonia throws down a precipitate neutral solutions of glucina, which is soluble in solutions of tash.

But sulphuretted hydrogen gas occasions no precipitate.

(11.) Litmus paper is reddened by neutral solutions of ucina.

(12.) The salts of glucina in general are decomposed by a d heat.

(13.) Many of the salts of glucina are insoluble in water.

(14.) When glucina, moistened with nitrate of cobalt, is eated before the blowpipe it does not become blue, but ark grey or black.

6. When the glucina obtained in the above described mode as dissolved in muriatic acid in Berzelius' analysis a small rtion of white matter remained which had the following operties:—

(1.) When heated before the blowpipe with carbonate of da it did not form a glass.

(2.) With borax it fused into a transparent glass, which by ning became milk white.

From these two characters he concluded that the substance s columbic acid. But the evidence seems hardly sufficient determine its identity with that acid.

7. The undissolved portion of No. 3., collected on the filter to be dried, ignited, and weighed. It is then dissolved in uriatic acid, and the solution mixed with potash ley in great cess. This alkali dissolves the alumina which is at first ecipitated, and leaves peroxide of iron, which is to be parated, washed, dried, ignited, and weighed. Its weight ing subtracted from that of the whole precipitate dissolved the muriatic acid gives that of the alumina.

8. Vauquelin, in his analysis of the emerald of Peru, found oxide of iron but oxide of chromium. After separating the ca, he added caustic potash in great excess to the solution. e-dissolved the glucina and alumina at first thrown down, precipitated a lilac-coloured powder, which became green ore the blowpipe; and when fused with borax or biphoste of soda, it gave a fine green glass quite similar in our to the emerald. When boiled with nitric acid to ness, and potash poured upon the residue, a lemon-yellow oured solution was obtained, which being mixed with a soion of nitrate of lead, gave a fine yellow precipitate, and th nitrate of mercury, a red precipitate.* From these

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* Jour. des Mines, vii. 94.

properties there could be no doubt that the matter was oxide of chromium.

EXAMPLE V.

Analysis of the Topaz.

This mineral is a compound of silica, alumina, and fluoric acid. No good method of determining the weight of fluoric acid has been hitherto discovered. In the third example I described the method employed by Bonsdorff; in this I shall give the way in which Berzelius attempted to determine it.

1. The topaz, reduced to a fine powder, is to be mixed with four times its weight of anhydrous carbonate of soda, and exposed for an hour in a platinum crucible to a strong red heat. From the matter thus treated, the alkali is to be washed off completely, and dissolved in water, so that nothing remains but a white powder. Berzelius was of opinion that the alkaline solution would contain the whole fluoric acid. But as it might contain also a little silica and some alumina, carbonate of ammonia was added to it as long as any precipitate fell. The precipitate being separated by the filter, the liquid was slowly concentrated by placing it in a warm place to drive off the excess of ammonia. During this concentration a little more earthy matter fell.

2. The white powder of No. 1. not dissolved in water, together with the portion separated from the alkaline solution, was collected on a filter and well washed. It was then dissolved in dilute muriatic acid. The solution, which was complete, was evaporated to dryness, and the dry residue being digested for some time in dilute muriatic acid, the silica was collected on a filter and treated in the way already described.

3. From the liquid thus freed from silica, and rendered previously nearly neutral by carbonate of ammonia, the alumina was precipitated by caustic ammonia. It was washed, dried, ignited, and weighed. Being dissolved in muriatic acid, it left no silica behind. We see from this, that when the original solution is evaporated, and the residue made sufficiently dry, the silica may be rendered quite insoluble. This is a case which never occurred to me in any of my analyses, though I am always at considerable pains in drying the residue. But I state it, that the reader may see the possibility of rendering the silica insoluble in muriatic acid.

4. The carbonate of soda solution, containing the fluoric id, was evaporated in a silver basin till its quantity was duced sufficiently to make it convenient for examination. was then saturated with muriatic acid, and left for twenty-ur hours in a temperature of 86°, to give time for the car-nic acid to escape. The liquid was then raised to the iling temperature, and neutralized with caustic ammonia, ded slightly in excess. It was then put into a flask, mixed th a solution of muriate of lime, and the vessel being corked quickly as possible, it was left to become clear. The ar liquid was drawn off, and a new portion of boiled water ded. It was again left to become clear, and the fluor spar oduced by mixture of the muriate of lime with the fluate of da was collected on the filter, washed, dried, and ignited. this substance a little muriatic acid was added to ascertain ether any carbonate of lime was mixed with the fluor spar.

From the weight of fluor spar thus obtained, it was easy to termine the quantity of fluoric acid contained in the mineral. r fluor spar is a compound of

Fluorine, . . .	2·25
Calcium, . . .	2·5
	4·75

o that every 4·75 grains of fluor spar are equivalent to 2·25 rains of fluorine, or 2·375 grains of fluoric acid. Or if we ultiply the fluor spar obtained by 0·474, we obtain the eight of fluorine.

This method of Berzelius is probably capable of consider-ble exactness, when the mineral containing fluoric acid is ee from lime, as is the case with the topaz. But when lime present it is obvious that the fluoric acid must be in com-ination with the lime, and carbonate of soda does not seem pable of decomposing fluor spar completely.

Klaproth's method of determining the quantity of fluoric id in the topaz was nearly the same as that of Berzelius. he liquid from which the silica and alumina had been parated was neutralized by nitric acid, evaporated to a mall quantity, and then mixed with lime water. Fluor spar ecipitated, from the quantity of which he deduced the eight of fluoric acid in the mineral.*

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* Beiträge, iv. 176.

EXAMPLE VI.

Analysis of Chrysoberyl.

The constituents of this mineral are silica, glucina, alumina, and protoxide of iron. Seybert detected a little oxide of titanium in the specimens which he analyzed, but I could detect none of that substance in the chrysoberyls from Brazil which I examined, though I repeated the analysis three times, and Dr. Thomas Muir, at my request, made a fourth analysis of the same mineral, with the same object in view.

1. The chrysoberyl reduced to the finest possible powder is mixed with four times its weight of anhydrous carbonate of soda, and the mixture exposed to a strong red heat for at least an hour in a platinum crucible.* The mixture was dissolved in muriatic acid. In general a portion of the mineral remains undecomposed. It is best to pound it again, and mixing it with four times its weight of carbonate of soda, repeat the ignition for at least an hour. The mixture is again treated with muriatic acid. By three or four repetitions of these processes (always pounding the undecomposed residue) I succeeded in obtaining a complete solution of the chrysoberyl in muriatic acid.

2. The muriatic solution is evaporated to dryness, and the silica separated in the way already described. The quantity found by Seybert varied from 4 to 6 per cent., but in my analysis I got no silica whatever.†

2. The muriatic acid solution freed from silica (should any be present) is reduced to a quantity sufficiently small for conveniently experimenting on ; it is then precipitated by caustic ammonia, and the whole is left at rest in a stoppered bottle till the precipitate has subsided to the bottom. The clear liquid is then drawn off by a sucker, and the bottle filled up with a solution of carbonate of ammonia ; the mixture is to be well shaken and left for twenty-four hours, agitating it occasionally. The carbonate of ammonia is then to be drawn off, and a new portion poured on, and treated in the same way. Thus the glucina is dissolved in the carbonate

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* Caustic potash has been commonly used for rendering chrysoberyl soluble in muriatic acid, but I found that carbonate of soda answered the purpose when the chrysoberyl was sufficiently pounded.

† The portion of silica which I obtained was just equivalent to what had been rubbed off the agate mortar during the pounding of the mineral.

ammonia, while the alumina and oxide of iron remains dissolved.

3. The alumina and oxide of iron being thoroughly washed e to be dissolved in muriatic acid, and the solution mixed ith potash ley in great excess. Alumina is kept in solution, hile the peroxide of iron remains undissolved. This perside is then to be separated, washed, ignited, and weighed.

4. The potash solution of alumina is mixed with sal amoniac, which throws down the alumina. It is collected on balanced filter, washed with hot water, dried, ignited, and eighed.

5. Mr. Seybert, in his analysis of chrysoberyl, employed ustic potash to render the mineral soluble in muriatic acid. fter four successive fusions with caustic potash, 0·17 of the uantity originally employed remained unacted on, and was t diminished by a subsequent fusion; he therefore had course to nitrate of barytes. Six parts of this salt were ixed with one part of the undecomposed residue. By four ccessive operations, the residue was reduced to $\frac{1}{100}$th part of e original quantity of chrysoberyl employed.

This matter was not acted on by alkalies or acids, when sed separately, but after having been previously calcined with austic potash, it readily dissolved in muriatic acid, yielding a olution of a pale yellow colour, which gave a reddish precipite with infusion of galls, a deep green precipitate with lphohydrate of potash, and a white precipitate with alkalies. rom these properties he considered it as titanic acid.*

EXAMPLE VII.

Analysis of Red Tourmalin, or Rubellite.

The constituents of this mineral are, boracic acid, silica, lumina, protoxide of iron, protoxide of manganese, lime, otash, lithia, and water. It is therefore a very complex bstance. But the method of separating all the constituents, cept the boracic acid and the lithia, has been given in the receding examples.

1. The method employed by M. C. G. Gmelin to estimate e boracic acid, is the following:—The tourmalin reduced to fine powder, is mixed with carbonate of barytes in the quisite quantity, and exposed in a platinum crucible to a

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* Silliman's Jour., viii. 108.

strong red heat for an hour and a half. The matter thus treated, is dissolved in muriatic acid, and the acid solution evaporated to dryness in a gentle heat. If the evaporation be conducted on the water bath, the portion of boracic acid which is driven off is quite inconsiderable. From this dry residue, the silica is to be separated in the usual way.

The residual liquid is to be precipitated by carbonate of ammonia, separated by the filter from the precipitated matter, evaporated to dryness, and the residual salt heated to incipient redness. No boracic acid can be driven off by this treatment, because that acid is in combination with ammonia, and because, during the heating no acid vapour escapes, as happens when sulphate of ammonia is treated in the same manner. The weight of the residue, after ignition, is to be carefully determined. It is then to be drenched with alcohol containing a little muriatic acid, and the alcohol is to be set on fire. This operation is to be repeated as long as the alcoholic flame shows the least tinge of green. In this way all the boracic acid which existed in the salt, under the form of borate of ammonia, is driven off. The residue is ignited again and weighed. The difference between the weight before and after the burning of the alcohol, gives the weight of the boracic acid thus given off.*

A better mode of determining the quantity of boracic acid in such a residue, would be to mix it with the requisite quantity of fluor spar and sulphuric acid, and then to raise the temperature gradually to ignition. The boracic acid would be driven off in the state of fluoboric gas, and the loss of weight would indicate its quantity. The amount of the sulphate of lime from the fluor spar could easily be estimated. The difficulty would be to determine the quantity of sulphuric acid which had united with the other ingredients in the matter under examination. But it might be determined by dissolving that residue (except the sulphate of lime) in muriatic acid, throwing down the sulphuric acid by muriate of barytes, and determining its quantity from the weight of the sulphate of barytes. Every 14·5 grains of sulphate indicating 5 grains of sulphuric acid.

Dr. Turner, some years ago, pointed out a very easy method of discovering the presence of boracic acid in minerals by means of the blowpipe. Mix the assay in powde

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* Poggendorff's Annalen, ix. 175.

with a flux composed of one part of pulverized fluor spar and four and a half parts of bisulphate of potash. The mixture moistened with a little water is attached to the extremity of a platinum wire, and exposed to the apex of the inner plane. Shortly after the fusion there appears a green colour round the flame, which soon disappears however, and is not again seen.*

The mode of separating lithia practised by C. G. Gmelin has been given in a former part of this work, and need not be repeated here.

When no other alkali but lithia exists in a mineral, the lithia may be obtained in the state of a sulphate by fusing the mineral with carbonate of barytes, separating the silica and the barytes in the way already explained: precipitating all the earthy matter from the residual liquid, filtrating, evaporating to dryness, and exposing the residual salt to heat to drive off the ammoniacal salts. The residual salt being mixed with sulphate of ammonia and ignited, nothing remains but sulphate of lithia.

When a mineral contains only a small quantity of lithia mixed with potash, or soda, or both together, Berzelius has proposed the following method of separating the lithia:—To the solution containing these alkalies add some phosphoric acid, and also a quantity of phosphate of soda, and then evaporate the whole to dryness. When the concentration has advanced to a certain point, the liquid becomes muddy, and when the dry residue is dissolved in water a white powder remains. It is the lithia-phosphate of soda. It is insoluble in a strong solution of phosphate of soda. Let it be collected in a filter, and washed with a little cold water. Dry this salt, expose it to a red heat, and weigh it. Every 100 grains of it are equivalent to 11·86 grains of lithia. The soda contained in it is equivalent to 27·12 per cent. This method will not succeed for a very obvious reason, if the solution contains any base whatever besides the alkalies. From phosphates of lime or magnesia, it may be distinguished by the blowpipe. If we mix it with carbonate of soda, and fuse it on platinum foil, it forms a transparent mass, which on cooling becomes opaque, whereas the earthy salts do not fuse at all.

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* Poggendorff's Annalen, vi. 490.

EXAMPLE VIII.

Analysis of Zircon.

When this mineral is pure it contains nothing but silica and zirconia. It is very difficult to decompose it so as to render it soluble in muriatic acid. I have succeeded by means of carbonate of soda, but the process is difficult, and requires too many repetitions to be advisable. The objection to the caustic alkaline hydrates is the ease with which they melt when heated. The consequence is, that when the crucible containing the mixture is put into the fire, its contents speedily fuse, boil, sputter up, and a portion is very apt to be lost. We succeed pretty well in preventing any such loss by covering the crucible with a close lid. But in that case it should be so small that the whole crucible, lid and all, may be exposed to a strong heat, otherwise a portion of the zircon escapes decomposition.

Berzelius adopted the following method, which is easy of execution:—Mix the zircon powder with thrice its weight of carbonate of soda, putting it in so that a hollow portion remains in the central part. Expose it for a quarter of an hour to incipient ignition, taking care not to fuse the mixture. Then put a quantity of hydrate of soda equal to the weight of the zircon into the central hollow, replace the crucible in the fire, and heat it slowly. The hydrate as it fuses is absorbed by the mixture. The consequence is, that it gives out its water slowly, and without sputtering. Raise the temperature to a white heat, and keep the mixture in that heat for half an hour. The fused mass is colourless if the zircon was pure, and the crucible when the process is conducted in this way is not acted upon.*

The whole is now dissolved in muriatic acid, and the solution treated as before described, in order to separate and obtain the silica. The liquid thus freed from silica is neutralized, and the zirconia thrown down by ammonia. It is washed, dried, ignited, and weighed.

Should the zircon contain iron, as is often the case, it is exceedingly difficult to free the zirconia completely from all admixture of that metal.

The characters of zirconia, by which it may be distinguished from other bodies, are as follows:—

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* Köng. Vet. Acad. Handl. 1824, p. 307.

.) When precipitated from a solution, washed, and dried
out the application of artificial heat, it is a pale yellow
y-looking matter, which dissolves readily in muriatic

When this hydrate of zirconia is ignited it glows at
noment of ignition, becomes white and insoluble in acids,
the exception of the concentrated sulphuric in which it
lves by slow digestion. When the solution of zirconia
uriatic acid is concentrated, it shoots into needle-form
tals.

2.) The solution of these crystals in water is colourless.
s an astringent and disagreeable taste.

3.) Potash throws down a bulky white precipitate, which
t re-dissolved by adding the potash in excess. Soda and
onia behave in the same way.

4.) A solution of carbonate of potash throws down a bulky
e precipitate, which is slightly soluble in a great excess
e carbonate. Carbonate of soda and the bicarbonates of
sh and soda act in precisely the same way. So does car-
te of ammonia, only that the zirconia is more soluble in
xcess of that carbonate than of carbonate of potash or
.

5.) Phosphate of soda throws down a bulky white preci-
e.

6.) Oxalic acid throws down a bulky precipitate, which is
ble in a great excess of muriatic acid.

7.) A concentrated solution of sulphate of potash throws
n, after a short interval, a white precipitate, which is
le in a large quantity of muriatic acid. When this pre-
ate is produced in a warm solution, it is nearly insoluble
ater and acids.

.) Prussiate of potash throws down a white precipitate.

.) Sulphohydrate of ammonia throws down the zirconia,
ulphuretted hydrogen gas occasions no precipitate.

0.) The salts of zirconia are decomposed by ignition.
y all redden litmus paper.

he blowpipe does not enable us to distinguish zirconia
other earthy bodies.

EXAMPLE IX.

Analysis of Thorite.

horina, when pure, is colourless, and after ignition is
ble in no other acid but the sulphuric, diluted with its own

weight of water. Even heating it with caustic fixed alkalies, or their carbonates, does not render it soluble in muriatic or nitric acid, as is the case with all the other earths, which become insoluble by ignition. These acids merely remove from thorina the foreign bodies with which it may be mixed. The hydrate of thorina dissolves readily in these acids while moist, but after it has been dried the solution takes place much more slowly.

When *potash* is dropt into a solution of thorina in an acid, a gelatinous precipitate falls, which is insoluble in an excess of the precipitant.

Carbonate of potash and *ammonia* also occasion a precipitate, which is re-dissolved in an excess of the precipitant. If the carbonate of potash be concentrated, the solution is effected very rapidly, but more slowly if it be dilute.

Phosphate of soda throws down a white flocky precipitate, insoluble in an excess of phosphoric acid.

Oxalic acid throws down a white heavy precipitate, insoluble in an excess of the acid.

Sulphate of potash occasions no change at first, but if it be concentrated and added in sufficient quantity, it gradually throws down the whole of the thorina.

Prussiate of potash throws down a white heavy precipitate, soluble in acids. Of course no precipitate appears unless the liquid be nearly neutral.

Sulphuretted hydrogen occasions no change, but sulphohydrate of ammonia throws down thorina.

Thorite consists essentially of silica, thorina, and water, but it contains also lime, peroxide of iron, oxide of manganese, peroxide of uranium, and minute quantities of magnesia, oxide of lead, oxide of tin, potash, soda, and alumina. It was analyzed by Berzelius in the following manner :—

1. The portion to be analyzed was ignited in a small retort to which a glass tube, containing chloride of calcium, was luted. The water was retained by the chloride of calcium, while a minute quantity of fluosilicic acid made its escape.

2. The portion thus treated was afterwards heated to ignition in a glass bulb, through which a current of hydrogen gas passed. The colour was changed from brownish-red to grey, water was evolved, and the mineral lost a certain portion of its weight.

3. The mineral thus treated was reduced to a fine powder, and digested with muriatic acid. The colour became yellow,

and a weak smell of chlorine was given out. Heat being applied, the smell of chlorine became stronger, and the whole was converted into a jelly. Being dried in the water bath, and afterwards digested in water acidulated with muriatic acid, it left a quantity of silica which was estimated in the usual manner.

4. The liquid thus freed from silica was mixed with caustic ammonia, and the precipitate well washed with boiling water. The filtered liquid was mixed with oxalic acid, and heated till the liquid at first muddy became clear. The oxalate of lime thus separated was ignited, and the lime estimated from it in the usual way. It contained mixed with it some manganese. To separate it the carbonate of lime was dissolved in muriatic acid. The solution was first mixed with bromine water, and then in a close flask with very dilute caustic ammonia till the acid was rather more than saturated. In twenty-four hours it had deposited a small quantity of yellow matter, which was oxide of manganese.

5. The liquid, freed from lime and manganese by oxalic acid, was evaporated to dryness, the ammoniacal salt was driven off by heat, and the residue being digested in water, left a little magnesia, not quite free from oxide of manganese.

6. The residual liquid being evaporated to dryness left a small quantity of chloride of potassium and chloride of sodium, which were separated from each other by chloride of platinum.

7. The precipitate obtained in paragraph 4, became dark coloured during the washing, on account of the oxide of manganese which it contained. It was dissolved while still moist in muriatic acid. A current of sulphuretted hydrogen was passed through the solution, which threw down a black precipitate. This precipitate was well washed, and then digested in sulphohydrate of ammonia which dissolved a little sulphuret of tin, too inconsiderable to be weighed. The remainder was treated with nitric acid till it was fully oxydized, a little sulphuric acid was then added, and the matter was heated till the excess of sulphuric acid was driven off. Water dissolved a metallic salt, from which ammonia threw down white flocks, which when examined by the blowpipe appeared to be oxide of tin.

8. The liquid which had been treated with sulphuretted hydrogen was evaporated to dryness in a gentle heat. It gelatinized, and left when dissolved in water a little silica.

9. The solution was mixed with an excess of caustic

alkali, which threw down a precipitate, but retained a small quantity of alumina in solution.

10. The precipitate dissolved readily in dilute muriatic acid, leaving a little oxide of manganese. It contained a trace of oxide of iron and of alumina.

11. The muriatic solution was neutralized by caustic ammonia, and concentrated by evaporation. After this sulphate of potash was added to it as long as it would dissolve it. A fine white precipitate fell, which was collected on a filter and washed with a saturated solution of sulphate of potash. It was then dissolved in boiling water, and precipitated by caustic potash. The precipitate was white, and did not acquire a yellow colour while drying, showing the absence of cerium. It was thorina, mixed with a very minute quantity of oxide of manganese, as was shown by heating it on platinum foil mixed with carbonate of soda.

12. The liquid which had been precipitated by sulphate of potash, was now precipitated by caustic potash. The precipitate was well washed, and then digested in carbonate of ammonia.

13. The matter insoluble in carbonate of ammonia was ignited and weighed. It was then dissolved in muriatic acid, and by means of succinate of ammonia, was decomposed into peroxide of iron and red oxide of manganese.

14. The solution in carbonate of ammonia was evaporated to dryness. The residue was digested in dilute acetic acid. This acid assumed a yellow colour, and caustic ammonia threw down a beautiful yellow precipitate, which became dark green by ignition, and was oxide of uranium.

15. The matter undissolved by the acetic acid, was yellowish grey. It gave a colourless solution in muriatic acid. The solution was mixed with tartaric acid and then with ammonia, without any precipitate appearing. Sulphuretted hydrogen threw down a minute quantity of sulphuret of iron.

16. The residue was evaporated to dryness in a weighed platinum crucible. The ammoniacal salts were driven off and the tartaric acid burnt. A small quantity of yellowish matter remained, which contained no yttria or titanic acid, but was thorina, mixed with some oxide of manganese.*

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* Köng. Vet. Acad. Handl., 1829, p. 3.

BOOK II.

OF THE ANALYSIS OF METALLIC ORES.

In the preceding book I have explained the methods of separating from each other the constituents of the first twelve genera of the second class of minerals, described in the first part of this work. The metallic ores, though they do not constitute so numerous, yet form a more difficult class; because the analyses of the different sorts being conducted upon different principles, will require a greater variety of illustrations before the young analyst can be made acquainted with the method of proceeding in the different cases which may present themselves to him. It will be the simplest mode of proceeding, to divide these ores into different groups, classing together those which bear the greatest resemblance to each other in the mode of analyzing them. Perhaps the ores may, without impropriety, be arranged (so far as their analysis is concerned) under the ten following heads:—

1. Alloys,
2. Seleniets,
3. Tellurets,
4. Arseniets,
5. Antimoniets,
6. Iodides,
7. Sulphurets and sulphur salts,
8. Oxides,
9. Chlorides,
10. Salts.

We shall treat of the methods of analyzing these different groups, in the ten following chapters.

CHAP I.

METHOD OF ANALYZING METALLIC ALLOYS.

There are twelve metals which occur in the mineral kingdom, either pure or only alloyed with other metals. These are iron, lead, bismuth, copper, mercury, silver, palladium, gold, platinum, iridium, titanium, arsenic, and antimony.

Sect. 1. *Iron.*

There are two species of minerals in which this metal occurs, either pure or merely alloyed with small quantities of other metals. These are, *native iron* and *meteoric iron.*

Iron in the metallic state, has a light grey colour with the metallic lustre, and is easily recognised by the effect which it produces upon the magnetic needle. It is hard and malleable; when cold, difficultly so, but when heated red hot it is very malleable, and can readily be hammered into any shape. When kept in a moist place, or when exposed to acid fumes, even in a dry place, it speedily rusts. When kept red hot in the open air, it is gradually converted into a red powder, distinguished by the name of peroxide of iron.

It dissolves with great facility in dilute sulphuric or muriatic acid, with the evolution of hydrogen gas. The saturated solution has a light green colour, an astringent taste, similar to that of ink, and when sufficiently concentrated, forms fine light green crystals.

In nitric acid, iron dissolves rapidly, and the solution assumes a dark reddish brown colour, in consequence of the nitrous gas evolved being absorbed by the acid.

Iron forms two oxides by combining with oxygen, the *protoxide* is a dark blue, and forms green-coloured solutions in acids; the *peroxide* is a fine red, and forms reddish or yellowish-brown solutions in acids. It will be proper to point out the action of re-agents upon solutions of each of these oxides, in sulphuric or muriatic acid.

1. *Protoxide of Iron.*

The solution, as has been already stated, is green, and has an astringent and inky taste.

(1.) Potash throws down a bulky precipitate in flocks. It is at first white, then becomes grey, and in an instant or two green; and this green colour deepens as the precipitate subsides to the bottom. If we attempt to dry it on a filter, it becomes yellow, and at last reddish-brown, by absorbing oxygen from the atmosphere. An excess of potash does not re-dissolve this precipitate. Soda acts precisely as potash does.

(2.) Ammonia produces the same effect as potash, when poured into a neutral solution of protoxide of iron in sulphuric or muriatic acid. But if the muriatic solution contains an excess of acid, or if we mix some sal ammoniac with it, then ammonia either throws down no precipitate, or precipitates imperfectly. By degrees, however, a small green precipitate falls, if the liquid be exposed to the air, and this precipitate becomes gradually reddish-brown, like that thrown down by potash or soda.

(3.) Carbonate of potash or soda, throws down a white precipitate without any effervescence ensuing from the evolution of carbonic acid gas. Sal ammoniac dissolves this precipitate, but on exposure to the air, a small greenish deposit appears and changes to reddish-brown.

Carbonate of ammonia produces the same precipitate, but more slowly.

The bicarbonates of these alkalies throw down the same precipitate, but an effervescence takes place at the same time from the escape of one-half of the carbonic acid in the state of gas.

(4.) Phosphate of soda throws down a white precipitate from a neutral solution of protoxide of iron, which after being sometime exposed to the air becomes green.

(5.) Oxalic acid, or binoxalate of potash, strikes a yellow colour when poured into a solution of protoxide of iron, and after some time a yellow precipitate falls, which is oxalate of iron. This precipitate is re-dissolved by the addition of muriatic acid. The oxalate of ammonia produces a similar precipitate.

(6.) Prussiate of potash throws down a precipitate, at first white, but instantly assuming a light blue colour, which gradually acquires a deeper shade in proportion as it absorbs oxygen from the atmosphere.

(7.) The infusion, or tincture of nutgalls, strikes a deep blue with the solutions of iron, so deep indeed, that it appears to the eye black, and constitutes common writing ink.

(8.) Sulphuretted hydrogen occasions no precipitate, but sulphohydrate of ammonia throws down a black precipitate. When this precipitate is exposed to the air, it becomes reddish-brown.* No excess of sulphohydrate of ammonia re-dissolves this precipitate.

(9.) The salts of protoxide of iron redden litmus paper.

(10.) The salts of protoxide of iron which do not dissolve in water, almost all dissolve in muriatic acid, and are again precipitated by ammonia.

(11.) In general we may detect the salts of protoxide of iron by the blowpipe. When fused with borax or biphosphate of soda, by the outer flame, a deep red bead is obtained, the

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* This enables us to distinguish iron from nickel and cobalt. The precipitate from these two last metals, by sulphohydrate of ammonia, remains black in the air.

colour of which becomes much lighter on cooling. When the bead is fused in the interior flame, a green-coloured bead is obtained, which colour disappears altogether when the glass cools, unless the proportion of iron be too great.

2. *Peroxide of Iron.*

The peroxide when pure, has a reddish-brown colour. It dissolves with facility in acids before it has been exposed to a red heat, but after ignition the solution takes place slowly. By far the best solvent of this oxide is muriatic acid.

(1.) Potash throws down a reddish-brown precipitate from the solution of peroxide of iron in acids. No excess of potash re-dissolves this precipitate.

Soda and ammonia produce the same effect.

(2.) The alkaline carbonates and bicarbonates, throw down a similar precipitate, but of a rather lighter colour.

(3.) Phosphate of soda throws down a white precipitate. If ammonia be added, the precipitate becomes brown, and after some time it totally disappears.

(4.) Oxalic acid occasions no precipitate in neutral solutions of peroxide of iron, but the liquid assumes a yellow colour.

(5.) Prussiate of potash throws down a very deep blue precipitate, which is insoluble in muriatic acid.

(6.) Sulphuretted hydrogen renders a neutral solution of peroxide of iron milky. Sulphur is precipitated, and the iron is reduced to the state of protoxide.

(7.) Sulphohydrate of ammonia throws down a black precipitate, insoluble in an excess of the re-agent. When this precipitate is exposed to the air, it becomes reddish-brown.

(8.) The salts of peroxide of iron, which are insoluble in water, dissolve in muriatic and dilute sulphuric acid, and are again thrown down from these solutions by ammonia.

(9.) The salts of peroxide of iron exhibit the same phenomena before the blowpipe, as those of protoxide.

Native iron was analyzed by Klaproth, and found to contain some lead and copper, with a trace of sulphur. It may be analyzed in the following manner:—

1. Dissolve 100 grains of it in muriatic acid. The solution should be effected in a small tubulated retort, from the beak of which there passes a glass tube, bent so as to pass to the bottom of a glass jar, containing a weak solution of nitrate of lead. Along with the hydrogen gas evolved, passes the sul-

phur of the iron, in the state of sulphuretted hydrogen gas. It is decomposed by the oxide of lead, the oxygen of that oxide uniting with the hydrogen of the sulphuretted hydrogen, and forming water, while the sulphur and lead combine to form sulphuret of lead, composed of

Lead, . . .	13
Sulphur, . . .	2
	15

So that every 15 grains of it contain 2 grains of sulphur. Collect the sulphuret of lead, wash, dry, ignite it, and weigh. From the weight of it we easily deduce that of the sulphur, which is $\frac{1}{7\frac{1}{2}}$ of the sulphuret.

2. Concentrate the muriatic acid solution, and set it aside or some time, the chloride of lead will be deposited in white ilky needles, which may be separated, washed, fused, and weighed. It is composed of

Lead, . . .	13
Chlorine, . .	4·5
	17·5

Hence the lead is 0·743 of the weight of the fused chloride.

3. Add a little nitric acid to the liquid thus freed from lead, and digest to peroxidize the iron. Concentrate, neutralize by ammonia, and throw down the iron by benzoate of ammonia. From the precipitate the quantity of iron is to be deduced in the way formerly explained.

4. Pour caustic potash into the solution thus freed from iron and lead; the copper is thrown down in the state of black oxide. Let it be washed, dried, ignited, and weighed. Four-fifths of its weight constitute the quantity of copper in the mineral analyzed.

Meteoric iron is distinguished from native iron by containing nickel, which appears to exist in a great variety of proportions. It may be analyzed in the following manner:—

1. Dissolve the meteoric iron in nitric acid. Concentrate the solution to make it as neutral as possible, dilute it with water, add sal ammoniac in sufficient quantity to form a double salt with the oxide of nickel; then throw down the iron by ammonia. Collect the precipitate on a filter, wash it, dry it, and ignite. It is peroxide of iron, every 5 grains of which is

equivalent to 3·5 grains of iron, or the iron constitutes $\frac{7}{10}$ths of the oxide.

2. Pour caustic potash into the liquid freed from iron, to precipitate the oxide of nickel. Should the nickel not be easily thrown down from the double salt, the liquid may be evaporated to dryness, and the ammoniacal salts driven off; then the residue must be dissolved in muriatic acid, and the oxide of nickel thrown down by caustic potash or soda. This oxide after ignition weighs 4·25, while the weight of the metallic nickel is 3·25. Hence $\frac{13}{17}$ths, or 0·765 of the oxide of nickel obtained is metallic nickel.

Sect. 2. *Titanium.*

It can scarcely be said that this mineral occurs native in the metallic state, but it was found at Merthyr Tydvil, at the bottom of the furnace in which iron had been long smelted, in fine metallic cubes; and I have a specimen of iron found in the same position at Muirkirk, in which a great deal of metallic titanium also occurs in small cubes. It has been observed also in a similar situation in other iron smelting houses. It is proper, therefore, that the young analyst should be aware of the mode of examining it.

Titanium is a fine red metal nearly of the colour of copper. It is brittle, and very hard, and crystallizes in cubes. It combines with two proportions of oxygen, and forms oxide of titanium, which is blue, and titanic acid, which is white. It is in the state of titanic acid that it is always obtained after solution.

In the metallic state titanium is scarcely soluble in acids; but when heated with caustic potash or soda it is readily oxidized, and converted into titanic acid.

(1.) Titanic acid, when precipitated from its solution in muriatic acid by an alkali, washed, and ignited, forms small lumps of a light brown colour, and a great deal of lustre. When the colour is reddish, the titanic acid contains some iron. When titanic acid is heated to redness it becomes lemon yellow, but loses this colour on cooling, and becomes white.

(2.) Titanic acid after ignition is insoluble in all acids. When in this state, if we mix it with carbonate of potash or soda, and heat the mixture to redness, the carbonic acid is driven off, and the titanic acid unites with the alkali. When such a mixture is fused, it assumes a crystallized form. Water dissolves the excess of the alkali, and leaves a supertitaniate of potash, insoluble in that liquid; but it dissolves in muriatic acid when assisted by a gentle heat. If we dilute the solution with water and boil it, the greatest part of the titanic acid falls down in the state of a white precipitate. If we throw the whole upon the filter, and attempt to wash the titanic acid, the liquid passes through transparent and colourless as long as it is acid, but as soon as the water becomes nearly pure it passes through the paper quite milky, so that by degrees all the titanic acid is washed away.

When titanic acid is precipitated from its solution in muriatic acid by boiling, it is very little soluble in acids; but if it be precipitated by an alkali, it may be washed in the filter, and dissolves completely in acids.

(3.) When potash, soda, or ammonia, or the carbonates or bicarbonates of these alkalies are dropt into a solution of titanic acid in muriatic acid, a white bulky precipitate falls, which does not dissolve on the addition of an excess of the precipitating medium; but if we add an excess of muriatic acid, the precipitate is again redissolved. The alkaline carbonates dissolve a very little of the precipitated titanic acid; but the quantity is so small that we cannot employ them to separate titanic acid from other bodies with which it may be mixed.

(4.) When the muriatic acid solution of titanic acid does not contain too much acid, as, for example, when it is added in such quantity as not to dissolve the whole of the titaniate of potash exposed to its action, if we drop into the solution dilute sulphuric acid, arsenic acid, phosphoric acid, tartaric acid, and especially oxalic acid, a white precipitate falls. This precipitate is again dissolved if we add an excess of the precipitating acid, or of muriatic acid. The oxalic acid precipitate, however, requires the addition of a little muriatic acid before it is completely redissolved.

Nitric acid, acetic acid, and succinic acid occasion no precipitate when they are employed.

(5.) When the muriatic acid solution contains as little excess of acid as possible, the tincture of nutgalls throws down an orange-red precipitate.* If titanic acid thrown down by boiling be mixed with the tincture of nutgalls, it also strikes an orange-red or brownish-yellow colour.

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* Prussiate of potash gives a similar precipitate, as far as colour is concerned.

(6.) Sulphuretted hydrogen throws down no precipitate from the muriatic acid solution of titanic acid.

Sulphohydrate of ammonia, added in excess, throws down a white precipitate, while sulphuretted hydrogen gas is disengaged. If the solution contain even a trace of iron, the precipitate is grey or black.

(7.) If a zinc rod is put into a solution of titanic acid in muriatic acid the liquid assumes a blue colour, and continues for some time clear, while at the same time hydrogen gas is evolved in consequence of the action of the free acid upon the zinc. By degrees a blue precipitate falls, which at last assumes a white colour. If we take out the zinc while the blue-coloured liquid remains transparent, and pour into it an excess of potash or ammonia, a blue precipitate falls, which gradually assumes a white colour, while at the same time hydrogen gas is evolved. When titanic acid thrown down by boiling is placed in contact with zinc, it assumes also a blue colour. If the quantity of titanic acid in the solution be very small, no blue colour appears. Iron and tin produce the same phenomena as zinc.

(8.) The compounds of titanic acid with bases are all, so far as is known, soluble in concentrated muriatic acid, even after having been exposed to a red heat. The solution is hastened by the application of heat; but we must take care not to apply too much, for if we throw down the titanic acid by heat it becomes insoluble in muriatic acid.

(9.) The appearances which characterize titanic acid before the blowpipe have been already described in a former part of this treatise.*

M. H. Rose has shown that the old method of precipitating titanic acid from its solutions by boiling does not give good analytical results. The best method is to throw it down by ammonia, taking care to use as small an excess of ammonia as possible. The difficulties attending the separation of titanic acid from other substances are so great, that chemists are not able at present to overcome them completely. The following observations, chiefly deduced from the researches of Rose, are all that I can offer:—

From the oxides of tin, mercury, silver, copper, bismuth, lead, and cadmium, titanic acid is readily separated by dissolving the mixture in muriatic acid, and passing a current of

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* See page 376.

huretted hydrogen through the solution. The oxides are wn down in the state of sulphurets, while the titanic acid ains in solution, and may be afterwards thrown down by ionia.

'he oxides of cobalt, nickel, zinc, and manganese, which, igh not precipitated by sulphuretted hydrogen, are precited by sulphohydrate of ammonia, may be separated from iic acid in the following way:—To the solution add a iderable quantity of tartaric acid, and then supersaturate ammonia. The tartaric acid prevents any precipitate appearing. Add a quantity of sulphohydrate of ammonia; oxides precipitate, but the titanic acid remains in solution. porate the solution to dryness, and expose the residue to d heat in an open platinum crucible till every thing comible is destroyed. The residual matter is now pure titanic This process succeeds also when we wish to separate iic acid from iron, with which it is frequently found in bination.

'o good method has yet been discovered of separating iic acid from zirconia, when they happen to be united, as metimes the case.

Vhen titanic acid occurs along with oxides of cerium and a, we must dissolve the whole in sulphuric acid, and boil solution. The titanic acid falls down, while the other two tances remain in solution. They are to be separated from other by the processes already described.

rom lime titanic acid is thrown down by ammonia; the ion must be filtered as much as póssible in a covered el, to prevent the lime from being thrown down during the ess in the state of a carbonate. From barytes and stron- we easily separate titanic acid by throwing down the er substances by means of sulphuric acid; ammonia preates the titanic acid from the fixed alkalies.

dissolving titanic acid, or the compounds of it, in muriatic the process is best conducted without applying heat; for e raise the temperature too high the titanic acid is preciied again, and the whole process stopped.

Sect. 3. *Lead.*

ead has been found native in the mineral kingdom, though in small quantity. The characters of this metal are so ing and so well known that it is easily recognised. It is t, heavy, malleable metal, having a bluish-white colour, and very soon tarnishing when exposed to the air. It dissolves readily in nitric acid. The solution is colourless, and readily yields octahedral crystals, having a sweet and astringent taste.

Lead forms three oxides, but only one of these, the protoxide, is soluble in acids. Hence it is the only one which occurs when native lead is dissolved in acids.

(1.) Protoxide of lead has a yellow colour, or sometimes a reddish-yellow. When heated to redness it melts readily, and in a white heat in open vessels sensibly evaporates. It is insoluble in water, but dissolves readily in nitric acid. The neutral solution of nitrate of lead has the following characters.

(2.) Potash or soda throws down a white precipitate, which is re-dissolved in an excess of the precipitating substance.

(3.) Ammonia throws down a white precipitate not soluble in an excess of the reagent.

(4.) The alkaline carbonates and bicarbonates throw down white precipitates not re-dissolved by an excess of the reagents.

(5.) Phosphate of soda throws down a white precipitate, which is soluble in a solution of pure potash or soda.

(6.) Oxalic acid throws down a white precipitate.

(7.) Prussiate of potash throws down a white precipitate.

(8.) Sulphuretted hydrogen and sulphohydrate of ammonia throw down a dark brown or black precipitate of sulphuret of lead.

(9.) A rod of zinc throws down the lead in the metallic state.

(10.) Sulphuric acid, or an alkaline sulphate, throws down a white precipitate, insoluble in acids, but soluble in caustic potash or soda. This last property enables us to distinguish precipitated sulphate of lead from sulphate of barytes, strontian, or lime.

(11.) Common salt, or any soluble chloride, occasions a white silky precipitate in concentrated solutions of lead. This precipitate is again dissolved by diluting the liquid with a sufficient quantity of boiling water.

(12.) Hydriodate of potash, or any soluble hydriodate, throws down a fine yellow-coloured precipitate, soluble in a great excess of the hydriodate.

(13.) Chromate of potash throws down a fine yellow precipitate, insoluble in dilute nitric acid, but soluble in pure potash or soda.

(14.) Most of the insoluble salts of lead dissolve in nitric acid, and sulphuric acid throws down a white precipitate from he solution. Sulphate of lead is not soluble in dilute nitric cid; but if we moisten it with sulphohydrate of ammonia, it ecomes black, and when fused with carbonate of soda on harcoal, a globule of metallic lead is obtained.

Native lead has never been analyzed. But I have repeatedly made experiments to determine the foreign metals contained in metallic lead. The only metals found were iron, copper, and silver; all in very minute quantity.

The iron was detected by dissolving 500 grains of lead in nitric acid, evaporating the solution till the excess of acid was driven off, and then precipitating the oxide of lead by sulphate of ammonia. The residual liquid when tested by prussiate of potash, sometimes indicated the presence of oxide of iron. This I attempted to separate by means of benzoate of ammonia. But in general the quantity from 500 grains of the lead was too small to be weighed.

Copper is a much more frequent constituent of lead than iron. After the lead has been thrown down from the nitric solution by sulphate of ammonia, if we concentrate the solution, and add a little ammonia, the presence of the copper is indicated by the blue colour which the liquid assumes. The copper may be thrown down by caustic potash, collected, ignited, and weighed. Every 5 grains of it are equivalent to 4 grains of metallic copper. I have found as much copper as 0·1 grain in 500 grains of lead.

Silver exists in such minute quantity in lead, that I have never been able to detect its presence by any other method than cupellation. A pound of lead is usually taken and kept at a red heat, in a muffle, on a test till the lead is all absorbed. The silver remains, and may be easily weighed, if its quantity be appreciable. But as the lead is usually deprived of its silver by cupellation before it is exposed to sale, it is not surprising that it seldom contains an appreciable quantity of that metal.

Sect. 4. *Bismuth.*

Bismuth occurs in a native state, and indeed constitutes its ost common ore. It is requisite therefore that the young alyst should be acquainted with the characters of this metal.

The only oxide of bismuth likely to come in the way of e analyst is the yellow oxide, formed when nitrate of bismuth exposed to a red heat.

(1.) This oxide dissolves in nitric acid, and forms a colourss solution, which when sufficiently concentrated yields crystals. When these crystals are put into water they undergo decomposition; a supersalt is dissolved, while a subsalt remains in the form of a white powder. An addition of nitric acid dissolves the whole by converting it into a supersalt.

(2.) Potash or soda throws down a white precipitate in solution of bismuth, which is not re-dissolved in an excess of the potash.

(3.) Ammonia acts in the same way.

(4.) The alkaline carbonates and bicarbonates throw down white precipitates, not dissolved in an excess of the precipitant.

(5.) Phosphate of soda throws down a white precipitate.

(6.) Oxalic acid occasions no change at first, but after some time a crystalline precipitate falls.

(7.) Prussiate of potash throws down a white precipitate not soluble in muriatic acid.

(8.) Sulphuretted hydrogen, or sulphohydrate of ammonia, throws down a dark brown or black precipitate which is a sulphuret of bismuth.

(9.) A rod of zinc precipitates bismuth in the metallic state.

(10.) Iodide of potassium throws down a brown precipitate, easily soluble in an excess of the precipitant.

(11.) Chromate of potash throws down a yellow precipitate, soluble in dilute nitric acid.

(12.) Before the blowpipe on charcoal a salt of bismuth mixed with carbonate of soda is easily reduced, and globules of metallic bismuth are obtained. These are white and brittle, breaking in pieces under the hammer, while globules of lead or silver are flattened. The charcoal becomes coated with yellow oxide of bismuth.

I am not aware that native bismuth has hitherto been subjected to analysis. But the principal impurity in the bismuth of commerce, which is merely native bismuth melted down, is sulphur. Native bismuth contains almost always traces of silver and arsenic. The mode of determining the sulphur will be given in a subsequent chapter. The silver is easily separated by the addition of a little muriatic acid. The silver is thrown down in the state of chloride, every 18·25 grains of which contain 13·75 grains of silver.

Arsenic is obtained when the bismuth is dissolved in nitric acid, and the solution being first rendered alkaline by the addition of ammonia is mixed with sulphohydrate of ammonia in excess. The whole is digested on the sandbath in a flask with a cork. The bismuth is precipitated in the state of sulphuret, while the arsenic remains in solution. Separate the sulphuret of bismuth by the filter, render the liquid that passes through acid by means of muriatic acid, and digest in a gentle heat till all smell of sulphuretted hydrogen is dissipated. The sulphuret of arsenic precipitates. Let it be collected on a filter and weighed. The mode of determining the quantity of arsenic which it contains will be given in a subsequent chapter, when treating of the sulphurets.

The best precipitant of oxide of bismuth is carbonate of ammonia. According to Liebig, carbonate of lime throws down bismuth from a cold solution of the nitrate, but not lead. We may employ this method of separating bismuth and lead.*

Sect. 5. *Copper*.

Native copper is a pretty common inhabitant of the mineral kingdom, usually in crystals, strings, or plates. All the specimens of it which I have examined were remarkably pure.

Copper has a well known red colour, and is malleable. It dissolves readily in nitric acid, forming a fine blue solution, yielding deliquescent crystals, which possess considerable causticity. In sulphuric acid and muriatic acid it does not dissolve, unless the solution be aided by the presence of nitric acid. But the black oxide of copper dissolves readily both in sulphuric and muriatic acid. The sulphuric solution is blue, the muriatic green. The salts of copper however neutral redden vegetable blues.

(1.) Potash or soda poured into a neutral solution of copper in an acid throws down a bulky blue precipitate, which is hydrated black oxide. When this precipitate is boiled with an excess of potash it becomes black, and quickly subsides. But if the quantity of potash be insufficient to decompose the salt completely, the precipitate is green, being a subsalt of copper.

(2.) A little ammonia being added to a solution of copper, a green precipitate falls, which speedily dissolves in an excess of ammonia, and the solution assumes a blue colour. This blue colour is much deeper than that produced by ammonia in a solution of nickel, and is characterized besides by

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* Ann. de Chim. et de Phys. xlviii. 293.

a shade of red which the nickel solution wants. If we boil the ammoniacal solution of copper with potash, a black precipitate falls and the liquid becomes colourless.

(3.) Carbonate of potash throws down a blue precipitate which boiling renders black and dense. Bicarbonate of potash throws down a green precipitate, easily dissolved by an excess of the precipitant. The solution then has a light blue colour.

(4.) Carbonate of ammonia in small quantity throws down a greenish white precipitate, which is re-dissolved by the addition of more carbonate. The solution has the same blue colour as that given by caustic ammonia, and when boiled with potash a black dense precipitate falls.

(5.) Phosphate of soda throws down a greenish white precipitate, which dissolves in ammonia, and forms a blue liquid. Potash boiled with this solution throws down a heavy black precipitate.

(6.) Oxalic acid throws down a greenish white precipitate.

(7.) Prussiate of potash throws down a reddish brown precipitate insoluble in muriatic acid.

(8.) Sulphuretted hydrogen, or sulphohydrate of ammonia, throws down a dark brown or black precipitate, which is bisulphuret of copper. It is not soluble in an excess of the sulphohydrate.

(9.) A rod of zinc throws down copper in the metallic state, so does a rod of iron.

(10.) Iodide of potassium throws down a white precipitate. It is re-dissolved in an excess of the precipitant.

(11.) Chromate of potash throws down a reddish brown precipitate, which dissolves in ammonia, forming an emerald green solution. It dissolves also in dilute nitric acid.

(12.) The salts of copper are easily detected by the blowpipe. When fused with borax, or biphosphate of soda, they communicate a fine green colour to the outer flame, and a dirty brownish red to the interior flame. When fused with carbonate of soda on charcoal, the copper is reduced to the metallic state.

The best precipitant of copper when alone in a solution is caustic potash or soda. It may be separated from iron by a current of sulphuretted hydrogen, which throws down the copper without acting on the iron.

Sect. 6. *Mercury.*

Mercury occurs occasionally in the earth in the metallic state, in small drops scattered through the rock in which it is found. It is usually pure. The presence of any foreign metal would be detected by the mercurial drop wanting its usual fluidity, or dragging a tail, as it is called. In such case the foreign body is easily obtained by distilling off the mercury.

Mercury is so well characterized by its white colour and its fluidity, that it cannot be confounded with any other metal. The best solvent of it is nitric acid. The solution is colourless, and crystallizes when sufficiently concentrated. This is the solution of mercury usually formed. The action of reagents upon it is as follows:

(1.) Potash throws down a black precipitate, insoluble in an excess of the reagent. Soda and ammonia act in the same way.

(2.) Carbonate of potash throws down a dirty yellow precipitate, which boiling renders black. Bicarbonate of potash throws down a white precipitate, which boiling renders black.

The action of carbonate of ammonia is nearly the same as that of carbonate of potash.

(3.) Phosphate of soda throws down a white precipitate.

(4.) Oxalic acid throws down a white precipitate.

(5.) Prussiate of potash occasions a white gelatinous precipitate.

(6.) Sulphuretted hydrogen throws down a black precipitate. Sulphohydrate of ammonia throws down a black precipitate, insoluble in an excess of the precipitant, and also in ammonia. It dissolves partially in a solution of pure potash, leaving a black powder, which proves on examination to be running mercury. When the filtered alkaline solution is supersaturated with an acid a black precipitate falls, which is sulphuret of mercury.

(7.) Muriatic acid, or common salt, or any soluble chloride, throws down a white precipitate.

(8.) A bar of zinc or copper throws down the mercury in the metallic state.

(9.) Iodide of potassium forms a greenish-yellow precipitate, soluble in an excess of the precipitant.

(10.) Chromate of potash throws down a red precipitate.

(11.) If we mix a salt of mercury with carbonate of soda, and heat the mixture to redness in a glass tube, shut at one end, running mercury sublimes and coats the tube in the form of a grey powder, which assumes the form of globules when rubbed with a glass rod.

The best way of determining the quantity of mercury in any salt is to reduce it to the metallic state. Suppose the mercury to exist in solution in the state of suboxide. Pour muriatic acid or sal ammoniac into the solution; the metal is thrown down in the state of chloride. Put this chloride into a flask, pour upon it concentrated muriatic acid, and then add a concentrated solution of chloride of tin, to which a sufficient quantity of muriatic acid has been previously added to render it perfectly clear. Boil the mixture for two or three minutes and then cork it up; the mercury falls to the bottom in the state of a black powder, which gradually forms larger globules. When the flask is cold pour off the liquid and wash the mercury with water, acidulated with muriatic acid, till it is quite clean. It must then be dried and weighed.

When the mercury is in the state of peroxide, if in combination with nitric acid, that acid must be destroyed by muriatic acid, or if it be in combination with any other acid, the salt may be put into the flask and treated as above directed: the result will be the same.

Sect. 7. *Silver.*

Native silver occurs very frequently in the mineral kingdom; indeed a great proportion of the silver from the American mines exists originally in that state. Native silver is seldom pure, it almost always contains copper, and sometimes antimony or arsenic. Whatever be its constituents we must begin the analysis by dissolving the native silver in nitric acid. The solution, if the silver be pure, is colourless, crystallizes when concentrated, and is very corrosive. The action of reagents upon this solution is as follows:—

(1.) Potash throws down a light brown precipitate, insoluble in an excess of the precipitant, but soluble in ammonia.

(2.) Ammonia, when added in very small quantity, throws down a brown precipitate, instantly dissolved by the addition of more ammonia.

(3.) Carbonate of potash or soda throws down a white precipitate, soluble in ammonia. Bicarbonate of potash or soda acts in the same way.

(4.) Carbonate of ammonia produces a white precipitate, soluble in an excess of the carbonate.

(5.) Phosphate of soda throws down a yellow precipitate, soluble in caustic ammonia; but pyrophosphate of soda throws down a white precipitate.

(6.) Oxalic acid throws down a white precipitate, soluble in ammonia.

(7.) Prussiate of potash throws down a white precipitate.

(8.) Sulphuretted hydrogen or sulphohydrate of ammonia throws down a white precipitate.

(9.) Muriatic acid, or any chloride, throws down a heavy white curdy precipitate, soluble in ammonia, but insoluble in dilute acids.

(10.) Iodide of potassium throws down a white precipitate with a shade of yellow. It dissolves in an excess of the precipitant, and very sparingly in ammonia.

(11.) Chromate of potash throws down a dark reddish-brown precipitate, soluble in dilute nitric acid, and in ammonia.

(12.) A bar of zinc throws down silver in the metallic state. The sulphate of iron produces the same effect.

If the native silver contain no other foreign metal but copper, we may dissolve it in nitric acid, throw down the silver by common salt, and afterwards the oxide of copper by potash. From these precipitates the quantity of silver and copper is determined, by the methods already explained.

When silver is alloyed with antimony or arsenic, the compound is dissolved in nitric acid. The solution is put into a flask, and supersaturated with ammonia; then a quantity of sulphohydrate of ammonia is poured in, the flask is corked, agitated, and left for some time. The antimony or arsenic is kept in solution, while the silver is precipitated in the state of sulphuret. This sulphuret is to be washed, dried, and weighed. It is composed of

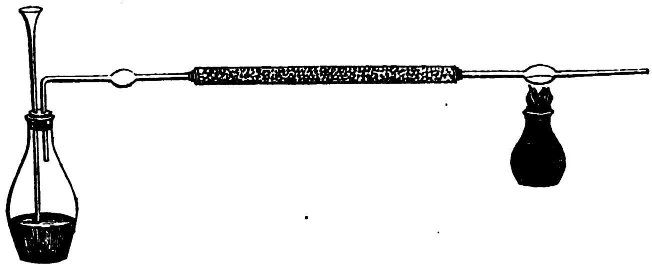
Sulphur, . .	2
Silver, . . .	13·75
	15·75

So that 0·873 of the sulphuret is silver.

From the solution the sulphides of antimony and arsenic are thrown down, in the way which will be immediately explained. The sulphuret of antimony always falls first, and the sulphuret of arsenic last.

The sulphides of arsenic and antimony intimately mixed are weighed, and then divided into two nearly equal portions. One portion is treated in a flask with fuming nitric acid cautiously added to acidify the sulphur, and muriatic acid is added to render the solution complete. Tartaric acid is now added to the solution, and the sulphuric acid precipitated by chloride of barium, and its weight ascertained. This gives the weight of the sulphur in the mixed sulphurets of antimony and arsenic obtained.

The other half of these sulphurets is put into a glass bulb, to which two glass tubes are soldered at opposite sides. A current of dry hydrogen gas is made to pass through the bulb, being generated in a flask connected with the bulb by a glass tube, in which a quantity of dry chloride of calcium is placed to dry the gas. When the tube and bulb are filled with hydrogen gas, heat is applied to the bulb, the sulphur and arsenic are driven off, and nothing remains but the antimony, which is to be weighed after the apparatus is cold. Knowing the weight of the sulphur and antimony in the mixed sulphurets, it is easy to deduce the weight of the arsenic.



Sect. 8. *Palladium.*

Native palladium occurs mixed with the platina grains from South America, and was first discovered and described by Dr. Wollaston. It consists of palladium alloyed with a little platinum and iridium. The metal seems to occur in considerable quantity in Brazil, though in what state I have never learned; but about twelve years ago large ingots of it were brought from that country to London, where they were exposed for sale.

The best solvent of palladium is aqua regia; the solution has a deep reddish-brown colour, and an astringent taste. The action of reagents on this solution, rendered as neutral as possible, is as follows:—

(1.) Potash or soda throws down a deep yellowish-brown precipitate, insoluble in an excess of the precipitant, but soluble in muriatic acid.

(2.) Ammonia throws down a reddish-white precipitate, which gradually assumes a whiter colour. When heat is applied, the whole dissolves, with the exception of a small quantity of white matter.

(3.) Carbonate or bicarbonate of potash occasions no precipitate.

(4.) Carbonate of soda throws down a brown precipitate, but the solution retains a brown colour. Muriatic acid readily dissolves the precipitate.

(5.) Carbonate of ammonia destroys the colour, but produces no precipitate.

(6.) Phosphate of soda throws down a brown precipitate; the liquid continuing brown.

(7.) Oxalic acid throws down no precipitate.

(8.) Prussiate of potash occasions at first no precipitate, but after a considerable interval a thick stiff jelly of a green colour appears.

(9.) Cyanodide of mercury throws down a yellowish-white gelatinous precipitate.

(10.) Nitrated suboxide of mercury throws down a greenish-black precipitate.

(11.) Protochloride of tin throws down a dark brown precipitate.

(12.) Sulphuretted hydrogen or sulphohydrate of ammonia throws down a black precipitate.

(13.) A rod of zinc throws down a black powder.

It will be best to defer explaining the mode of separating palladium from platinum and iridium till we come to speak of platinum: the one description may serve for all.

Sect. 9. *Gold.*

This metal occurs most commonly in the metallic state, but seldom or never pure. It is almost constantly alloyed with silver, frequently with copper, and sometimes, though seldom, with iron.

Gold has a well known yellow colour, is soft, very malleable, and very heavy. It does not dissolve in sulphuric, nitric, nor muriatic acid; the best solvent of it is aqua regia; the solution is yellow and caustic. It consists of chloride of gold. The neutral chloride of gold is the only solution of that metal that can be conveniently obtained. It exhibits the following phenomena with reagents:—

(1.) Potash occasions no precipitate at first, but by degrees the liquid assumes a greenish tinge, and a small quantity of black matter falls down.

(2.) Ammonia throws down a dirty yellow precipitate, which is fulminating gold, and is re-dissolved by an excess of the ammonia.

(3.) Carbonate or bicarbonate of potash throws down nothing, but carbonate of ammonia throws down a yellow precipitate.

(4.) Phosphate of soda occasions no change.

(5.) Oxalic acid produces a greenish-black colour, owing to the separation of metallic gold, which gradually falls to the bottom.

(6.) Prussiate of potash strikes an emerald green colour, but occasions no precipitate.

(7.) Cyanodide of mercury throws down no precipitate, unless the chloride of gold be mixed with alcohol, when a slight reddish-yellow matter may be thrown down.

(8.) Nitrated suboxide of mercury throws down a black precipitate.

(9.) Sulphate of iron throws down a blue coloured precipitate, which is metallic gold.

(10.) Protochloride of tin, in diluted solutions of gold, produces a purple red colour; in concentrated solutions it throws down a dark purple precipitate.

(11.) Iodide of potassium strikes a black colour, and a yellowish-green precipitate falls.

(12.) Sulphuretted hydrogen throws down a black, and sulphohydrate of ammonia a dark brown precipitate.

(13.) A plate of zinc throws down the gold in the metallic state.

An alloy of gold and silver is to be beaten out into a thin plate, and digested in aqua regia. The gold is dissolved, but the silver remains behind in the state of chloride. It is to be separated, washed, dried, fused, and weighed. 18·25 grains of this chloride are equivalent to 13·75 grains of silver.

The gold solution being mixed with nitrated suboxide of mercury, the whole gold is precipitated, and the precipitate, when dried and ignited, leaves metallic gold.

Should the alloy contain copper, it will remain in solution ter the gold has been precipitated, and its presence will be iown by the green colour of the liquid. The copper may thrown down in the state of black oxide by potash. Should slight excess of nitrated suboxide of mercury remain in lution, it will not injure the accuracy of the result, because e red heat will dissipate the mercury and leave only the ide of copper. Every 5 grains of black oxide of copper e equivalent to 4 grains of the metal.

If iron be present, it must be thrown down by benzoate of mmonia before precipitating the copper.

Sect. 10. *Platinum.*

This metal, like gold, has hitherto been found only in the etallic state, in small grains, or in lumps, sometimes of very onsiderable size. This native platinum is never pure. The etal is always alloyed with iridium, rhodium, palladium, os- ium, copper, and iron; and the separation of all these metals om each other, is attended with very considerable difficulties. t will be requisite, before attempting to explain the methods hich have been thought of for that purpose, to give the aracters by which platinum, rhodium, iridium, and osmium, e distinguished, that the young analyst may be able to cognise these metals when he meets them.

Platinum, like gold, can be dissolved only in aqua regia. he solution is dark reddish-brown, and very astringent. It in this solution that the peculiarities of platinum are best bserved.

(1.) Potash throws down a yellow precipitate, consisting of tassium-chloride of platinum. This precipitate is not sen- bly dissolved in acids, but when we add an excess of potash d apply heat, a solution is effected. When the excess of tash is saturated with muriatic acid, the precipitate again pears.

(2.) Ammonia produces the same effect as potash. The ecipitate is not re-dissolved by acids, but it dissolves in an cess of ammonia when the action is assisted by heat; and hen the excess of ammonia is saturated with muriatic acid, a hite precipitate appears.

(3.) Carbonate of potash throws down the same precipitate, hich is not re-dissolved by an excess of the precipitant. icarbonate of potash and carbonate of ammonia, act precisely the same way.

(4.) Carbonate of soda occasions no precipitate.

(5.) Phosphate of soda throws down no precipitate.

(6.) Oxalic acid occasions no sensible change.

(7.) Prussiate of potash throws down a yellow precipitate, and the liquid assumes a deeper colour.

(8.) Cyanodide of mercury throws down nothing.

(9.) Nitrated suboxide of mercury throws down an abundant yellowish-brown precipitate.

(10.) Sulphate of iron throws down nothing.

(11.) Iodide of potassium gives the liquid a deep brownish-red colour, and occasions a lighter coloured brown precipitate. When heat is applied, the glass acquires a metallic coating.

(12.) Protochloride of tin gives the liquid a deep brownish-red colour, but precipitates nothing.

(13.) Sulphuretted hydrogen renders the liquid brown, and by degrees a brown precipitate falls, which at last becomes black. Sulphohydrate of ammonia produces the same effect, but the precipitate re-dissolves in an excess of the sulphohydrate.

(14.) A plate of zinc throws down a black powder.

(15.) When a red heat is applied to the chloride of platinum, the chlorine is driven off, and metallic platinum remains in grains or in a spongy state.

Rhodium.

Rhodium is a white metal, of so difficult fusion, that hitherto it has been obtained only in grains. In the metallic state it is insoluble in all acids, and even in aqua regia. But when in combination with another metal, as platinum, aqua regia is capable of dissolving it. When fused with bisulphuret of potassium it is oxidized, and may be dissolved. It may be dissolved also by fusion with phosphoric acid. It is oxidized also when fused with pure potash or with saltpetre. The solutions of oxide of rhodium and the chloride, have a rose-red or brownish-red colour, and exhibit the following phenomena with re-agents:

(1.) Potash occasions no precipitate, but when the mixture is boiled, a gelatinous brownish-yellow matter falls.

(2.) Ammonia occasions, after some time, a copious yellowish precipitate, which is completely soluble in muriatic acid. The solution has a yellow colour.

(3.) Carbonate of potash at first occasions no precipitate, but after some time a yellowish sediment falls. Carbonate of soda and carbonate of ammonia act in the same way.

(4.) Phosphate of soda throws down no precipitate.

(5.) Oxalic acid produces no sensible change.

(6.) Prussiate of potash throws down no precipitate.

(7.) Sulphate of iron occasions no change.

(8.) Protochloride of tin produces a dark brown colour, but throws down no precipitate.

(9.) Iodide of potassium deepens the colour, and occasions at last a slight precipitate.

(10.) Sulphuretted hydrogen produces at first no change, but by degrees a brown sediment falls, though the colour of the liquid continues. Sulphohydrate of ammonia throws down a brown precipitate, not soluble in an excess of the reagent.

(11.) A plate of zinc throws down the rhodium in the metallic state, under the form of a black powder.

Iridium.

Iridium is a white metal, like platinum, and requires so high a temperature to fuse it, that it has never been obtained in any other state than that of powder. It is very heavy, though its specific gravity has not yet been determined with accuracy. It is insoluble in nitric, muriatic, dilute sulphuric acid, and even in aqua regia. But it dissolves in this last liquid when alloyed with a sufficient quantity of platinum. By fusion with saltpetre, it may be converted into an oxide. It oxidizes spontaneously in fine powder when simply exposed to the atmosphere, as I have repeatedly observed. The chloride is the only solution of this metal whose action with reagents has been studied. Its colour is dark red, or dark reddish-brown.

(1.) Potash changes the colour of the liquid to a dirty green, and a very small quantity of a brownish-black precipitate falls. When heat is applied to this mixture, it gradually assumes a blue colour, which becomes deeper and deeper. When the blue liquid is evaporated, a slight bluish precipitate at first falls, but the dry mass is white with a tint of green. When it is digested in water, a blue powder remains undissolved, and the solution is colourless.

(2.) Ammonia added in excess destroys the colour as much as potash does, and throws down merely a trace of brownish-black deposit. When the liquid is long boiled, so that most of the excess of ammonia is driven off, it begins to assume a blue colour, but this colour is never so pure as when potash is employed. The colour is improved when the liquid is not boiled but left in a vessel exposed to the air.

(3.) Carbonate of potash throws down at first a copious light reddish-brown precipitate, but which gradually dissolves again, and the colour of the solution becomes much lighter. There remains a mere trace of a brownish-black precipitate. When the mixture is boiled it does not assume a blue colour. When we evaporate the whole to dryness, and treat the dry residue with water, a little blue coloured matter remains undissolved, and the solution after a time assumes also a blue colour.

(4.) Bicarbonate of potash produces at first no change, but by degrees the liquid loses its colour, just as when potash, or carbonate of potash is used, but no precipitate appears.

(5.) Carbonate of soda destroys the colour like the other carbonates. Boiling at first occasions no change, but if we continue the process, a blue colour at last appears. Carbonate of ammonia occasions the same phenomena.

(6.) Phosphate of soda at first produces no change, but after a considerable interval of time the liquid becomes nearly colourless.

(7.) Oxalic acid occasions at first no sensible alteration, but by degrees the colour of the liquid is destroyed.

(8.) Prussiate of potash produces the same effect.

(9.) Cyanodide of mercury occasions no change.

(10.) Nitrated suboxide of mercury throws down a light brown precipitate.

(11.) Sulphate of iron occasions no change at first, but after a considerable interval of time, a dirty greenish precipitate falls.

(12.) Protochloride of tin throws down a light-brown precipitate.

(13.) Iodide of potassium discolours the solution, but occasions no precipitate.

(14.) Sulphuretted hydrogen at first discolours the liquid. After a considerable time, a brown precipitate of sulphuret of iridium falls. Sulphohydrate of ammonia occasions a brown precipitate, dissolved by a small excess of the precipitating reagent. When muriatic acid is poured into this solution, sulphuret of iridium falls down.

(15.) A plate of zinc throws down the iridium in the metallic state, under the form of a black powder.

Osmium.

Osmium is usually obtained in the state of a black powder, but when in a compact state it has the metallic lustre. When heated in a close vessel it undergoes no change, neither meltng nor volatilizing, but in the open air it flies off when heated under the form of an oxide, which has a strong and characterstic smell. Nitric acid dissolves it and converts it into osmium acid, and both acids are volatilized together. The change is more easily effected by aqua regia. The chloride of osmium is obtained, when osmium previously mixed with chloride of potassium is exposed to a current of chlorine gas while elevated to a red heat. The chloride of osmium has a red colour, but its solution in water is yellow. This chloride produces with reagents the following phenomena:

(1.) Potash occasions at first no change, but when the mixture is heated, it assumes a black colour, and a black precipitate falls, after which the solution becomes lighter coloured.

(2.) Ammonia occasions at first no alteration, but after some time the liquid becomes brown, and a brown precipitate falls.

(3.) Carbonate of potash produces no sensible change at first, but after a considerable interval a black precipitate falls, and the liquid assumes a bluish colour. Bicarbonate of potash acts in the same way.

(4.) Carbonate of soda acts as carbonate of potash, only the liquid has not quite so strong a blue colour.

(5.) Carbonate of ammonia acts as ammonia.

(6.) Phosphate of soda occasions no change.

(7.) Oxalic acid is equally inefficacious.

(8.) Prussiate of potash and cyanodide of mercury throw down no precipitate.

(9.) Nitrated suboxide of mercury throws down a yellow precipitate.

(10.) Sulphate of iron occasions no change.

(11.) Protochloride of tin throws down a brownish precipitate.

(12.) Iodide of potassium occasions no change at first, but after some time a black precipitate falls, and the liquid assumes a blue colour.

(13.) Sulphuretted hydrogen produces no change at first, but after a considerable interval, a yellow precipitate falls. Sulphohydrate of ammonia throws down a yellow precipitate which is soluble in an excess of the precipitant.

(14.) A plate of zinc throws down a black powder from solutions of osmium.

The analysis of platinum ore is attended with considerable difficulties. We must begin by separating all the foreign matter, and leaving nothing but the small plates of crude platinum.

After every thing that seems to be foreign has been removed, we must digest the purified ore in dilute muriatic acid. The object of this is to free it from the coating of peroxide of iron with which it is often covered, and to free it from any metallic iron with which it may be mixed.

The ore must now be ignited, but it should be previously weighed, because the ignition occasions an increase of weight by peroxidizing some of the iron.

The constituents of this complicated ore, arranged according to the relative amount of the constituents, are platinum, iron, iridium, copper, rhodium, palladium, and osmium.

1. Dissolve the portion of ore taken for analysis (30 grains are sufficient) in aqua regia, in a glass retort furnished with a receiver, which must be kept constantly cold. The liquid which distils over is yellow, and carries with it some of the ore, which, rising in a fine cloud during the effervescence, is driven over mechanically by the nitrous gas evolved. Distil off the acid till the liquid in the retort assumes the consistence of a syrup, and congeals on cooling. The saline mass is dissolved in the smallest possible quantity of water, and the solution poured off with the proper precaution. The acid which had distilled over is poured back upon the undissolved residue in the retort, and distilled again. This in general is sufficient to dissolve the whole of the ore. Distil as before to a syrup, re-dissolve, and pour off. If the liquid in the receiver be not colourless, it must be poured back into the receiver and re-distilled.

2. The colourless distilled liquid is diluted with water, and saturated with ammonia, or if this should be thought too expensive, with hydrate of lime, taking care however to leave a slight excess of acid. Put the solution into a flask, and add to it sulphuretted hydrogen water in excess. Then shut the mouth of the flask, (which ought to be nearly filled with the solution), and let it remain at rest till the precipitate formed in it have time to subside. The clear liquid is now drawn off with a syphon, and the precipitate, which consists of sulphuret of osmium, is collected on a weighed filter, washed,

dried, and weighed. It contains about 51 per cent. of osmium.

3. Should the liquid smell of chlorine after dissolving the saline mass, we must allow it to digest till this smell vanishes. If a precipitate appear, it is oxide of palladium, which must be re-dissolved. The whole is then poured into a weighed filter, and the matter collected on this filter is to be washed and dried. It consists of grains of iridium ore and sand, which could not be separated previous to the analysis. Sometimes, besides these substances, a black powder appears, which looks like charcoal, and which passes through the filter during the washing of the other matter. It is peroxide of iridium, and it is produced when the aqua regia used for the solution contains too much nitric acid.

4. The filtered solution is mixed with twice its bulk of alcohol, of the specific gravity of 0·833, so that the mixture may contain about 60 per cent. of alcohol. A concentrated solution of chloride of potassium in water is now added, so long as it throws down a precipitate. This precipitate is a mixture of potassium-chloride of platinum, and potassium-chloride of iridium, contaminated with the same salt of rhodium, and even of palladium. The precipitate has a fine lemon-yellow colour, when it is free from iridium; but when iridium is present it assumes all the shades of red, from deep yellow to cinnabar. It is collected on a filter and washed with spirits of the specific gravity of 0·896, and holding in solution a little chloride of potassium. The washing is continued till the liquid which passes through the filter gives no precipitate with sulphuretted hydrogen water.

5. The washed double chlorides on the filter are dried and mixed as equably as possible with their own weight of carbonate of soda. The filter, with what of the precipitate cannot be removed, is burnt, and its ashes mixed with carbonate of soda, and added to the rest of the double salt. Put the whole into a porcelain crucible, and heat it gently till it is quite black throughout. This process could not be conducted in a platinum crucible, because the crucible would be corroded, and a portion of the metal mixed with the chlorides under investigation.

By this process the double salts are decomposed, and the platinum reduced to the metallic state. The iridium and rhodium become oxidized, and remain in such a state as to permit the separation of the platinum from them by solution.

The heated saline mass is washed with water till the greater part of the salt is dissolved. Dilute muriatic acid is then added to the remainder to extract the alkali combined with the oxides of iridium and rhodium. The mass is washed, dried, ignited, and weighed.

Now mix it with five or six times its weight of bisulphate of potash, and fuse the whole in a platinum crucible, covered with a lid. The rhodium is oxidized and sulphurous acid given out, and a solution of the oxidized rhodium takes place in the salt, which acquires a red or black colour, according to the portion of rhodium taken up. This operation is repeated several times; indeed as long as the salt acquires colour.

6. The quantity of rhodium may be estimated two ways: if we wash, ignite, and weigh the undissolved platinum, the loss of weight indicates the peroxide of rhodium, which contains 71 per cent. of metal; or we may mix the acid solution of rhodium with an excess of carbonate of soda, evaporate the mixture to dryness, and ignite the dry salt in a platinum crucible. Upon dissolving it again in water, the peroxide of rhodium remains behind; it is collected, washed, dried, and reduced by hydrogen gas in the way formerly explained. The rhodium thus obtained may contain palladium; this is extracted by aqua regia. The solution of palladium is neutralized, and then precipitated by cyanodide of mercury. The weight of the palladium thus obtained is of course abstracted from that of the rhodium.

7. After the separation of the rhodium, the metallic mass is next treated with dilute aqua regia by digestion, in which platinum is separated. The solution appears very dark in consequence of the presence of peroxide of iridium, but when this oxide has fallen to the bottom the colour will be found to be a pure yellow. The clear liquid is decanted; concentrated aqua regia mixed with common salt is now poured over the residue, and the mixture is evaporated to dryness. The common salt is added to prevent the formation of protochloride of platinum. The solution thus obtained consists chiefly of platinum, but it contains also a little iridium. Upon dissolving the dry mass the peroxide of iridium remains behind; as it is apt to pass through the filter when washed with pure water, we must wash it with a solution of common salt, and afterwards with a solution of sal ammoniac, to get rid of the common salt. It is now burnt with the filter, reduced by hydrogen gas, and weighed. The solution of soda salt, which contains

iridium, is mixed with carbonate of soda, evaporated to dryness, and heated to redness. The product is a mixture of platinum and peroxide of iridium, which being freed by washing from soluble salts and then treated with aqua regia, leaves the peroxide of iridium. Caustic ammonia still precipitates from the solution a trace of brown oxide of iridium, which, however, is not quite free from platinum. The peroxide of iridium is reduced, and the metal is added to the quantity formerly obtained.

8. To learn the weight of the platinum we must subtract that of the peroxide of rhodium from the common weight of the platinum, peroxide of rhodium, and peroxide of iridium. The weight of iridium obtained must be increased 12 per cent. to convert it into peroxide, and this augmented weight must also be deducted from the sum total. The remainder, after these two subtractions have been made, is the weight of the platinum.

9. We have still the alcoholic solution of No. 4. to examine. We put it into a flask furnished with a ground stopper, and pass a current of sulphuretted hydrogen through it till it is saturated. The flask is then closed, and left for twelve hours in a warm place, by which time a precipitate will have subsided. It is now filtered, and the alcohol evaporated off. During this concentration an additional precipitate falls, which is added to the former.

This precipitate consists of sulphuret of iridium, sulphuret of rhodium, sulphuret of palladium, and sulphuret of copper, while the filtered liquid contains iron, a little rhodium and iridium, and a trace of manganese. During the evaporation of the alcohol, a greasy and disagreeable smelling sulphuret is deposited, which cannot be washed out. After the solution has been entirely washed away, this substance can be removed by pouring a little ammonia into the vessel. The solution of it is put into a platinum crucible and evaporated to dryness, after which the other moist sulphurets are also put into the same crucible and roasted as long as sulphurous acid is produced. When the roasting is ended, muriatic acid is poured over the mass, subsulphates of copper and palladium dissolve, forming a green or yellowish-green solution, while the oxides of iridium and rhodium, with a small quantity of platinum, remain undissolved.

10. The muriatic acid solution is mixed with chloride of potassium and nitric acid, and evaporated to dryness. A dark

coloured saline mass is obtained, which contains chloride of potassium, potassium-chloride of copper, and potassium-chloride of palladium. The first two of these salts being soluble in alcohol of the specific gravity of 0·833, are extracted by that spirit. The palladium salt then alone remains; it is collected on a filter and washed with alcohol. It contains 28·84 per cent. of palladium.

The spirituous solution of the copper salt contains a trace of palladium, too small to be of any consequence in the analysis. The solution is evaporated to get rid of the alcohol, and the copper precipitated by caustic potash. It is in the state of black oxide, every 5 grains of which are equivalent to 4 grains of metallic copper.

11. The roasted sulphurets (No. 9.) which could not be dissolved in muriatic acid are fused with bisulphate of potash, the process being repeated as long as the salt becomes coloured. By this means the rhodium is dissolved out. The residual matter thus deprived of rhodium is treated with aqua regia, which dissolves a little platinum, and leaves peroxide of iridium.

12. The concentrated solution from which the sulphurets were precipitated, contains only iron in the state of protochloride, a small quantity of iridium and rhodium, and a trace of manganese. It is mixed with a sufficient quantity of nitric acid, and boiled till the iron is fully peroxidized. The peroxide of iron is then precipitated by caustic ammonia, and the precipitate is washed, ignited, and weighed. The peroxide of iron is reduced by hydrogen gas, and the metal is dissolved in muriatic acid, which, towards the end, must be warmed. There remains undissolved a small quantity of black powder. This black powder is ignited in an open vessel, by which it acquires the same degree of oxidizement as the peroxide of iron. It is then weighed, and its weight is deducted from that of the peroxide of iron. Every 5 grains of this peroxide are equivalent to 3·5 grains of metallic iron. The black powder is a mixture of iridium and rhodium, in a state not yet well understood.

13. The solution which was precipitated by caustic ammonia, still contains iridium and rhodium. It is mixed with carbonate of soda in sufficient quantity to decompose the ammoniacal salts, and then evaporated to dryness. The residue, after gentle ignition, is dissolved in water. The metallic oxides remain undissolved. The quantity of manganese con-

tained in the metallic oxides, is scarcely greater than to enable the operator to detect it. It may be extracted from the washed oxides by muriatic acid. But when 30 grains only of the ore are analyzed, the manganese is too minute to be capable of being weighed.

The preceding mode of analyzing the ore of platinum, is the one put in practice by Berzelius, in his elaborate paper on the metals in native platinum, inserted in the Memoirs of the Stockholm Academy for 1828. It is exceedingly intricate, and too complicated to give exact results. But it is the only mode hitherto devised by analytical chemists. Before it was published, we were not in possession of any method of separating these singular metals from each other with any pretensions to accuracy. The method suggested by Berzelius, therefore, though imperfect, is still of considerable value as a first step, which, no doubt, will be gradually improved upon and simplified, till it reaches the requisite degree of precision.

Sect. 11. *Arsenic.*

Arsenic occurs occasionally in the mineral kingdom in the state of metal, and is then known by the name of *native arsenic*. It is found, however, much more frequently combined with other metals constituting arseniets, or united to sulphur, forming a sulphur acid or a sulphide of arsenic. We shall therefore defer the account of the mode of separating arsenic from other bodies till we come to treat of the sulphur salts. In this section it will be sufficient to give the characters of the metal, and the mode of detecting it or its acids, when they occur in the mineral kingdom.

Arsenic is a white metal, very brilliant while quite fresh, and not unlike iron, but speedily tarnishing and becoming black on the surface. It is soft and very brittle, and rather light. When heated, it sublimes before it melts. If it be heated almost to redness in the open air, it takes fire, and burns with a very pale white flame, giving out a white smoke having a strong smell of garlic. It combines with two proportions of oxygen, forming two acids, the arsenious and arsenic. It is by converting arsenic into arsenic acid, that its quantity in any compound can be most accurately determined. This, in general, is easily done, by dissolving the ore in nitric acid, or nitro-muriatic acids. It is requisite to be acquainted with the effect of re-agents upon this acid, that we may know it when it occurs.

(1.) An arseniate when mixed with carbonate of soda, and exposed to the action of the blowpipe on charcoal, gives out the well-known odour of garlic, which characterizes the vapour of metallic arsenic. When mixed with charcoal powder and a little boracic acid, and heated in a glass tube closed at one end, they deposit on the cold part of the tube, a metallic mirror of arsenic, easily distinguished by the characteristic odour producible by heat.

(2.) When an arseniet is in solution, sulphuretted hydrogen gas immediately strikes a yellow colour, and if the solution be acidulated with muriatic acid, a bright yellow precipitate falls. This precipitate is soluble in sulphohydrate of ammonia; while the precipitate from cadmium, which resembles the arsenical precipitate very closely, is insoluble in that liquid.

(3.) Sulphohydrate of ammonia occasions no precipitate in a solution containing a neutral arseniate; but if muriatic acid be added, sulphuretted hydrogen is disengaged, and a bright yellow precipitate falls.

(4.) Nitrate of silver throws down a brown precipitate, easily soluble in nitric acid or in ammonia.

(5.) Chloride of barium, chloride of calcium, and lime water, occasion white precipitates, very readily soluble in sal ammoniac, provided the liquid does not contain free ammonia.

(6.) Nitrate of lead throws down a white precipitate, which, when heated on charcoal before the blowpipe, gives out a white smoke, characterized by the well-known garlic odour of arsenic.

The action of re-agents upon salts containing arsenious acid, closely resembles their action on arseniates. They may be distinguished from arseniates by the *yellow* precipitate which they let fall when mixed with nitrate of silver. The precipitate by nitrate of silver from an arseniate, is brown.

Sect. 12. *Antimony.*

Antimony occurs occasionally in the metallic state, and is then distinguished by the name of native antimony. But it is much more frequently met with combined with sulphur. It will be better on that account to reserve an account of the method of separating antimony from other metals, till we come to treat of the sulphur salts. Here it may be proper to point out the characters of antimony, by which it may be recognised when it occurs.

Antimony has a silver, or rather zinc white colour, a good deal of lustre, and a plated texture. It is brittle, so that it can be easily reduced to powder in a mortar. When heated to redness, it melts and gives out copious white fumes of oxide of antimony, which are deposited in shining crystals. Nitric acid oxidizes antimony with rapidity, but does not dissolve it. The best solvent is aqua regia; the solution is brown, contains always an excess of acid, and is very corrosive.

Antimony unites with three different proportions of oxygen, and forms oxide of antimony, antimonious acid, and antimonic acid.

The oxide of antimony is white, but when heated in a retort, it melts into a yellow mass and may be easily sublimed, when it forms brilliant needle-form crystals. It dissolves in muriatic acid, and the solution becomes milky when diluted with water, but a considerable excess of acid re-dissolves the precipitate. This acid solution of oxide of antimony produces the following phenomena with re-agents.

(1.) Potash produces a white precipitate, insoluble in an excess of the potash.

(2.) Ammonia acts in the same manner, and so do carbonate of potash, bicarbonate of potash, and carbonate of ammonia.

(3.) Phosphate of soda throws down a white precipitate, and so does oxalic acid. These precipitates are occasioned by the water in which the re-agents are dissolved.

(4.) Prussiate of potash throws down a white precipitate, which does not dissolve in muriatic acid.

(5.) Sulphuretted hydrogen produces a beautiful orange-red precipitate. Sulphohydrate of ammonia throws down the same precipitate, but it is easily re-dissolved by adding an excess of the sulphohydrate.

(6.) A plate of zinc throws down antimony in the metallic state, and in the form of a black powder.

Salts containing oxide of antimony, if mixed with carbonate of soda, and heated on charcoal by the interior flame of the blowpipe, are reduced. The bead of antimony produced remains long in the melted state, and gives off a thick white smoke. When the smoke ceases, the globule of antimony becomes covered with a net-work of crystals of oxide of antimony.

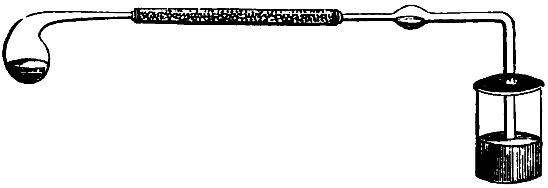
The phenomena with antimonious and antimonic salts, are so nearly the same, that it is unnecessary to enter into details.

CHAP. II.

METHOD OF ANALYZING SELENIETS.

SELENIUM has been found in the mineral kingdom, united to zinc, lead, copper, silver, and palladium. Of these seleniets, the most abundant is seleniet of lead, which has been found in considerable quantity in the Hartz mines. We are indebted to M. H. Rose for the first analysis of these seleniets. He proceeded in the following way :—

A small globular cavity was blown in the centre of a glass tube. To one extremity of this globe, a small glass tube, 4 inches long, was attached by the blowpipe, and to the other extremity, a wide glass tube, about 12 inches long, and bent at a right angle in the middle. These tubes, with the glass cavity, were weighed, the seleniet to be analyzed was then put into the glass globe, and its weight determined. The narrow tube was then attached to an apparatus for preparing chlorine, which was dried by passing it through an intermediate tube containing chloride of calcium. The extremity of the wide tube was plunged into the bottom of a vessel filled with water. The tubes being filled with chlorine gas, the bulb is heated gently by a spirit of wine lamp. Chloride of selenium is formed and volatilized. The protochloride is first formed. It flows in the form of an orange-coloured liquid along the tube into the water. Selenium is deposited, but again dissolved by the chlorine which passes into it. Afterwards nothing is formed but perchloride of selenium, which condenses in the tube, and would shut it up altogether unless it were very wide. This chloride must frequently be driven by a lamp along the tube, till it passes into the water. The chlorine should pass over very slowly, for if the bubbles of gas rise too rapidly through the water, some of the chloride of selenium



might be carried off by it before it had time to be decomposed by the water. After the passage of the chlorine has continued five or six hours, all the metals in the bulb are converted into chlorides. The process is at an end when no more chloride of selenium is sublimed. The bulb is then allowed to cool with the requisite precautions to prevent its cracking, when the chloride of lead, which had been in fusion, congeals. The portion of the tube containing chloride of selenium, is now to be cut off, and this chloride is carefully washed into the water containing the rest of it. After washing and drying the tube, it is weighed with the glass bulb containing the metallic chloride. We must take care not to apply too much heat to the bulb, otherwise some of the chloride of lead might be volatilized.

Muriatic acid is added to the water containing the chloride of selenium, and then a sufficient quantity of sulphite of ammonia to precipitate the selenium. For this purpose, the whole must be digested for a considerable time, and even boiled, to ensure the deposition of the whole selenium. The selenium is now to be collected on a weighed filter, washed, dried, and weighed.

If the mineral analyzed be seleniet of lead, what remains in the bulb is merely chloride of lead, composed of

Chlorine, . . .	4·5
Lead, . . .	13
	17·5

Or, every 17·5 grains of it contain 13 of lead, or 0·743 of the weight is lead.

Should silver be present as well as lead, we separate the two metals by boiling the chlorides in water. The chloride of lead dissolves, while that of silver remains.

Should iron be present, it is sublimed along with the chloride of selenium, and easily separated by means of ammonia, which throws it down in the state of peroxide.

Should cobalt occur along with the lead, it will remain in the bulb in the state of chloride, mixed with chloride of lead. Water will dissolve the two chlorides completely. Mix sulphuric acid with the solution, and evaporate to dryness to get rid of the muriatic acid and the excess of sulphuric acid. This residue being digested in water, the sulphate of cobalt will dissolve, while the sulphate of lead remains in the state of a white powder. Let it be washed, ignited, and weighed.

Multiply the weight by 0·684, the product is the weight of the metallic lead.

The cobalt may then be precipitated by caustic potash. The precipitate washed, dried, and ignited, is protoxide, each 4·25 grains of which are equivalent to 3·25 grains of metallic cobalt. So that if we multiply the weight of the oxide by 0·765, the product will be the quantity of metallic cobalt.

Caustic potash does not throw down cobalt completely, but the small residue falls when sulphohydrate of ammonia is added to the solution. This precipitate when dried, is sulphuret of cobalt. If we multiply its weight by 0·619, the product is the quantity of cobalt which it contains.

Should copper exist in the mineral along with lead, it is separated precisely in the same way as cobalt, by throwing it down, after abstracting the sulphate of lead, by caustic potash. When copper, lead, and silver, occur together, the chlorides of lead and copper are dissolved by boiling water, while the chloride of silver remains behind. Then the chlorides of lead and copper are converted into sulphates, and the sulphate of copper being dissolved, the metal is thrown down in the state of oxide by caustic potash.

When seleniet of mercury is mixed with seleniet of lead, the method of analysis is a little different. The chloride of mercury (corrosive sublimate) sublimes along with the chloride of selenium, and both are dissolved in the water, but the oxide of mercury cannot be completely precipitated by an alkali. But sulphohydrate of ammonia throws it down completely. Add to the aqueous liquid containing the two volatile chlorides ammonia, and then sulphohydrate of ammonia. Collect the sulphuret of mercury on a weighed filter, wash it and weigh it. If the weight be multiplied by 0·862, the product gives the weight of the mercury contained in it. Having thus separated the mercury, add muriatic acid till the liquid becomes acid, and drive off the sulphuretted hydrogen. After oxidizing by aqua regia the sulphuret of selenium deposited, and adding it to the liquid, let the selenium be thrown down by sulphite of ammonia in the way already described.*

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* Ann. de Chim. et de Phys. xxix. 113.

CHAP III.

ANALYSIS OF ANTIMONIETS.

Only two minerals are at present known which are composed of antimony united to another metal, and both in the metallic state. These are *antimoniet of nickel* and *antimoniet of silver*.

Antimoniet of nickel may be dissolved in nitromuriatic acid, and the antimony thrown down by sulphuretted hydrogen, after having added a quantity of tartaric acid to prevent the precipitation of any of the nickel. The sulphuret of antimony is collected on a filter, washed, and dried, and reduced by hydrogen gas. The nickel may be thrown down by caustic potash, washed, dried, ignited, and weighed. The weight multiplied by 0·765 gives the quantity of metallic nickel in the oxide.*

When antimoniet of silver is digested in nitric acid the silver is gradually dissolved, while the antimony remains behind in the state of an oxide. This oxide may be dissolved in muriatic acid, precipitated by dilution with water, and the remainder by an alkali. The precipitated oxide is reduced by hydrogen, and its weight estimated. The silver solution is to be thrown down by common salt, and the resulting chloride collected, washed, dried, fused, and weighed. Should any iron exist in the mineral it will be found in the nitric acid solution after the silver has been thrown down, and may be precipitated by potash, or ammonia, washed, dried, ignited, and weighed.

CHAP. IV.

ANALYSIS OF ARSENIETS.

Arsenic, in the metallic state, exists in the mineral kingdom in combination with no fewer than seven metals, constituting seven different mineral species. These are

Sesquiarseniet of iron,

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* See Stromeyer, Poggendorff's Annalen, xxxi. 134.

Arseniet of manganese,
Arseniet of nickel,
Arseniet of cobalt,
Arseniet of copper,
Arseniet of silver,
Arseniet of antimony.

Arseniet of iron may be digested in aqua regia as long as any thing is taken up. The undissolved residue is collected on a filter, washed, dried, and weighed. Being exposed to a red heat, the sulphur mixed with this residue burns, and its quantity is determined by weighing the residue, and subtracting the amount of its weight from that of the original quantity. What remains now is part of the gangue with which the mineral was contaminated. Its amount is to be subtracted from that of the mineral subjected to analysis.

The solution contains sulphuric acid which is thrown down by chloride of barium, taking care that such an excess of acid exists in the liquid as will prevent the precipitation of any arseniate of barytes.

A current of sulphuretted hydrogen gas is now passed through the liquid till it is saturated, and smells strongly of that gas. It is put in a warm place, and left till all this smell is dissipated. The sulphuret of arsenic thrown down is collected on a filter, washed, dried, and weighed. It is a compound of 4·25 arsenic and 5 sulphur. Therefore, if we multiply the weight of sulphuret obtained by 0·459, the product will be the amount of the arsenic in the mineral. Or after weighing the sulphuret of arsenic we may digest it in aqua regia, determine the amount of sulphur that remains undissolved, throw down the sulphuric acid by chloride of barium, and determine the amount of the sulphur which it contains. The quantity of sulphur in the sulphuret being thus known, if we subtract it from the weight of the sulphuret of arsenic the remainder will be the weight of the arsenic in the mineral.

The iron in the solution has by the action of the sulphuretted hydrogen been brought into the state of protoxide. By digestion with nitric acid, or by a current of chlorine gas, it is to be brought to the state of peroxide, and then thrown down by ammonia, washed, dried, ignited, and weighed.

Should the solution besides iron contain cobalt and nickel, as is sometimes the case, the iron must be thrown down by benzoate of ammonia, and the oxides of nickel and cobalt, by austic potash. The nickel and cobalt must be separated from ach other by processes to be afterwards described.

Arseniet of copper may be dissolved in aqua regia. The olution must be rendered alkaline by an excess of ammonia, nd then digested in a close vessel with a considerable excess f sulphohydrate of ammonia. The copper is precipitated n the state of sulphuret. One half the weight of this sulphuret usually denotes the amount of the copper. But as this is not always the case the best way is to digest the sulphuret in nitric acid till the copper is dissolved, and then to throw it down by caustic potash or soda. It is obtained in the state of black oxide, every 5 grains of which are equivalent to 4 grains of metallic copper.

The solution containing the arsenic is diluted with water, and then mixed with as much muriatic acid as is sufficient to render it acid. Sulphuretted hydrogen is disengaged, and sulphuretted arsenic is precipitated. It must be collected on a weighed filter, washed, dried in a gentle heat, and weighed. Put as much of it as can be separated from the filter into a small glass flask, then weigh the filter with what remains on it to determine how much of the sulphuret of arsenic has been submitted to experiment. Pour aqua regia over the sulphuret in the flask and allow it to digest. The arsenic is converted into arsenic acid, and the sulphur partly acidified, and partly precipitated in the state of pure sulphur. Filter the solution to separate the unacidified sulphur, and precipitate the sulphuric acid by means of chloride of barium. Calculate the quantity of sulphur in the sulphate of barytes thrown down, and add it to the weight of the sulphur collected on the filter. The amount of this subtracted from that of the sulphuret of arsenic experimented upon gives the weight of arsenic contained in that arseniet. The only error likely to be committed is collecting the sulphur upon the filter before all the arsenic is dissolved. This must be carefully guarded against.

Should the arseniet of copper contain iron, as is said to be the case, that metal will be precipitated along with the copper in the state of sulphuret. We must digest the precipitated sulphurets in aqua regia till both the metals are completely dissolved. The solution must then be neutralized, and the iron thrown down by benzoate of ammonia, and afterwards the copper by caustic potash. From these precipitates the weight of the iron and copper is to be determined in the way already explained.

Arsenical silver, according to the analysis of Klaproth, contains silver, iron, arsenic, and antimony. It may be digested in nitric acid, which will dissolve the silver and arsenic, and most of the iron. Common salt will throw down the silver in the state of chloride. The iron and arsenic may be separated by the methods already pointed out.

The residue insoluble in nitric acid may be taken up by digestion in muriatic acid, except a little chloride of silver, which is to be washed, dried, fused, and weighed. Let the solution be precipitated by caustic potash, and the precipitate after being washed re-dissolved in muriatic acid. If we dilute the solution with water the antimony will precipitate. What remains in solution is peroxide of iron, which may be precipitated by caustic ammonia.

The method of separating *arsenic* and *antimony* has not been brought to the same state of perfection, as the separation of arsenic from the other metals treated of in this chapter. If the alloy consists of arsenic and antimony alone, the former metal may be sublimed from the latter by the simple application of heat. The alloy is put into a glass ball blown in the middle of a tube. A current of dry hydrogen gas is passed through it till all the common air is expelled. Then heat is applied to the ball and continued as long as arsenic sublimes. The arsenic must be driven along the tube and expelled by a small spirit lamp. After the process is finished the metallic antimony is weighed. The difference between its weight and that of the original alloy gives the amount of the arsenic driven off.

When the antimony and arsenic are in solution, or when they are combined with other bodies, this process cannot be applied. Mix the solution with tartaric acid to prevent the antimony from being precipitated when water is added. Dilute with water, and pass a current of sulphuretted hydrogen gas through the liquid till it is saturated, and apply heat to ensure the complete precipitation of the sulphurets. What precipitates first is sulphuret of antimony, and after a considerable interval the bright yellow precipitate of sulphuret of arsenic appears. Mix the precipitates by agitation, and collect them on a weighed filter. Let it be dried in a very gentle heat till it ceases to lose weight. After determining the weight of the whole, shake about one half into a flask. Warm the filter with the remainder, and weigh it; by this proceeding the exact quantity experimented on is known.

The portion shaken into the flask is very cautiously oxidized by aqua regia, beginning first by adding fuming nitric acid in small quantities at a time, and finally muriatic acid. Mix the solution thus produced with tartaric acid, and dilute it with water. Should any sulphur fall down it should be collected, dried, and weighed. The sulphuric acid in the solution is precipitated by chloride of barium, and the weight of sulphur in it determined. The knowledge of the weight of the sulphur gives us that of the arsenic and antimony together.

Another portion of the precipitated sulphurets is heated in an atmosphere of hydrogen gas, just as sulphuret of antimony is heated to determine how much antimony it contains. The sulphur from the antimony first sublimes, and then the sulphuret of arsenic. At last nothing remains but metallic antimony. Knowing by these two processes the weight of sulphur and of antimony in the mixed sulphuret, it is easy to deduce that of the arsenic.

When arsenic and antimony are together alloyed with other metals, these metals will remain in solution after the arsenic has been thrown down by sulphuretted hydrogen, provided they be metals not precipitated by sulphuretted hydrogen, as is the case with iron, manganese, nickel, and cobalt. After separating the arsenic and antimony, we must throw down these metals by sulphohydrate of ammonia, and analyze the sulphurets thus obtained by the methods hereafter to be explained.

CHAP. V.

ANALYSIS OF TELLURETS.

TELLURIUM is found in the mineral kingdom alloyed with lead, bismuth, and silver, under the forms of bitelluret of lead, bitelluret of silver, and telluret of bismuth. It occurs also in the state of native tellurium, and there are two ores of gold formerly found in Transylvania, and still existing in cabinets, which contain tellurium. These are white tellurium ore, and graphic ore of tellurium.

Tellurium is a brittle foliated metal, having the colour of silver, easily fusible, and capable of being sublimed at a heat below redness. When heated before the blowpipe it gives a blue tinge to the flame. It forms an oxide when heated in the open air, which has a white colour, and 5 grains of it are equivalent to 4 grains of the metal. Tellurium dissolves readily in nitric acid or aqua regia, and the solution is colourless. The oxide of tellurium is much more easily soluble in aqua regia than in nitric acid. This solution, brought as nearly as possible to a neutral state, exhibits the following phenomena with reagents:—

(1.) Potash throws down an abundant white precipitate, soluble in an excess of the precipitant. Ammonia, and carbonate and bicarbonate of potash, and carbonate of ammonia, act precisely in the same way. An excess of carbonate of potash strikes a green colour, which disappears on boiling the liquid, and does not again show itself.

(2.) Phosphate of soda throws down a white precipitate.

(3.) Oxalic acid throws down no precipitate.

(4.) Prussiate of potash occasions no precipitate.

(5.) Sulphuretted hydrogen throws down a brown precipitate, very similar to the precipitate thrown down by the same reagent from a solution of protoxide of tin. Sulphohydrate of ammonia throws down a similar precipitate.

(6.) A plate of zinc throws down tellurium in the metallic state, under the form of a bulky black matter.

The insoluble compounds of tellurium are generally soluble in muriatic acid.

Bitelluret of lead was found by Klaproth to contain lead, tellurium, gold, silver, copper, and sulphur.

Reduced to a fine powder it may be digested in aqua regia, and the solution separated while boiling hot from the residue, consisting partly of sulphur, and partly of sulphate of lead. Let the residue be weighed and the sulphur driven off. The residue is sulphate of lead, composed of 5 sulphuric acid and 14 oxide of lead. Hence every 19 grains of it are equivalent to 2 grains of sulphur, and 13 grains of lead in the metallic state.*

The solution thus freed from sulphur, on cooling deposits numerous crystals of chloride of lead. The liquid must be concentrated, and set aside to obtain as many of these crystals as possible. When washed and dried they are composed of

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* The silver, of which only a very minute quantity exists in the ore, will also be found in the residue in the state of chloride. It may be separated from the sulphate of lead by digesting the mixture in caustic ammonia.

4·5 chlorine, and 13 lead. Hence every 17½ grains of them contain 13 grains of lead.

The liquid thus freed from lead may be diluted with a little water, and then mixed with alcohol as long as a white precipitate continues to fall. After allowing the mixture to remain for some time in a warm place, collect this precipitate on a filter, and after washing it in alcohol, dissolve it in muriatic acid, and throw it down by caustic soda, taking care not to add the alkali in excess. When washed and dried it constitutes oxide of tellurium, every 5 grains of which are equivalent to 4 grains of metallic tellurium.

Distil off the alcohol, and dilute the concentrated solution with a little water, then add nitrated suboxide of mercury as long as a brown precipitate continues to fall. Collect this precipitate and fuse it with saltpetre; the gold will be obtained in the metallic state, melted into a globule.

The copper still remains in solution, but it may be thrown down by caustic potash. Even should a slight excess of the mercurial salt have been added it will not be injurious, because it will be driven off when we ignite the oxide of copper before weighing it.

Telluret of bismuth may be dissolved in nitric acid or aqua regia, and the solution is to be supersaturated with ammonia. After this sulphohydrate of ammonia is added in excess, and the whole set aside for some time in a stoppered phial. Sulphuret of bismuth precipitates, and may be analyzed by the methods afterwards to be pointed out; or we may consider every 11 grains of this sulphuret to be equivalent to 9 grains of bismuth.

The solution containing the tellurium is precipitated by muriatic acid, warming the liquid till the odour of sulphuretted hydrogen is dissipated. Collect the sulphuret of tellurium on a filter, wash it and dry it, and dissolve it in aqua regia. Raise this liquid (which must always contain an excess of muriatic acid) to the boiling point, and then add sulphite of ammonia gradually till the whole tellurium be precipitated in the state of a black powder. In this state it is metallic tellurium, which must be washed, dried in a gentle heat, and weighed.

Bitelluret of silver contains nothing but tellurium, silver, and a trace of iron. It dissolves readily in nitric acid, and the solution is hastened by the application of heat.

Throw down the silver from this solution by means of muriatic acid; the residual liquid may be put into a warm place, and treated with successive portions of muriatic acid till all the nitric acid which it contained is decomposed. It may then be diluted with water, and after being heated it may be mixed with muriatic acid and sulphite of ammonia. The tellurium is thrown down in the metallic state under the form of a black powder. The process must be repeated till all the tellurium is thrown down.

The liquid remaining still contains iron. A current of chlorine may be passed through it to peroxidize this iron, and the peroxide may be thrown down by caustic ammonia.

The other ores containing tellurium may be analyzed by the methods now pointed out.

CHAP. VI.

ANALYSIS OF IODIDES.

THE only combination of iodine and a metal, hitherto met with in the mineral kingdom, is *iodide of silver.*

Iodine is a substance having a blackish colour, and something of the metallic lustre. It is volatile, and characterized by the fine violet colour which it assumes when converted into vapour. It dissolves slightly in water, though the quantity is sufficient to strike a beautiful blue colour when mixed with a jelly of starch in water. It is much more soluble in alcohol than in water, and the solution has a pretty deep brown colour. It dissolves in caustic potash or soda ley, and by the solution is converted into two acids; namely, hydriodic acid, which forms with the soda a soluble salt, and iodic acid, the combination of which with soda is much less soluble, so that it usually falls in the state of a white powder.

When nitrate of silver is dropt into a hydriodate a white matter falls, having considerable resemblance to chloride of silver. This precipitate, like chloride and bromide of silver, is insoluble in dilute nitric acid; caustic ammonia has but little action on it, whereas it readily dissolves chloride and bromide of silver. These two characters are sufficient to enable us to distinguish the iodide of silver from other bodies, and consequently to detect the presence of iodine in liquids.

When iodide of silver is digested in nitric acid it is not attacked unless the acid be very strong. When digested in muriatic acid it is partly decomposed, and the colour and smell of iodine become sensible when heat is applied. When the muriatic acid is subjected to distillation, the iodine passes into the receiver, and is deposited in crystals.

CHAP. VII.

ANALYSIS OF CHLORIDES.

THE only chlorides hitherto observed in the mineral kingdom are those of silver and mercury.

The analysis of *chloride of silver* is sufficiently simple. A quantity of the chloride is put into a globular cavity, blown in a glass tube, to which is afterwards attached an apparatus for disengaging hydrogen gas and drying it, by allowing it to pass through a glass tube containing fused chloride of calcium. When the apparatus is filled with hydrogen gas, the heat of a lamp is applied to the glass containing the chloride, and continued till the chlorine is disengaged under the form of muriatic acid gas, and the reduced silver remains behind. By weighing this silver, and deducting the weight from that of the original chloride, we determine the weight of the chlorine disengaged.

The analysis may be conducted in another way. We may mix together in a porcelain crucible 5 parts of carbonate of potash and 4 parts of carbonate of soda, amounting together to twice the weight of the chloride of silver to be analyzed. This quantity, reduced to powder, is intimately mixed with the carbonates. By applying the heat of a spirit lamp with a circular wick, the silver is reduced with the evolution of carbonic acid gas. We dissolve out the alkalies, and saturate them with nitric acid; we then throw down the chlorine which they contain by nitrate of silver. The chloride washed, dried, and fused, gives us the weight of the chlorine. This chloride, if the assay was pure, ought to weigh just as much as the quantity experimented on.

Should *chloride of mercury* occur in the mineral kingdom, as it is said to do, it is easily analyzed by digesting it with a solution of caustic potash or soda. The filtered solution contains the chlorine. We have only to saturate it with nitric acid, and throw the chlorine down by nitrate of silver.

The mercury might be estimated from the weight of the oxide. The only chloride likely to occur is calomel, from which potash separates suboxide of mercury, composed of 25 mercury and 1 oxygen. But it is more accurate to estimate the mercury by putting another portion of the chloride, previously reduced to powder, into a flask, and pouring over it first a quantity of muriatic acid, and afterwards of protochloride of tin. This mixture is heated to the boiling point, and then set aside to cool, after being well corked up. The mercury is thrown down in the metallic state, first as a black powder, but which runs into globules when heated with muriatic acid. It is to be carefully dried and weighed.

CHAP. VIII.

ANALYSIS OF OXIDES.

THE number of minerals existing composed almost entirely of one or more metallic oxides united together, is very considerable, and the processes requisite differ so much, according to the nature of the metallic oxide present, that we must treat of each metal separately.

Sect. 1. *Oxides of Iron.*

Iron combines with two different proportions of oxygen, and forms two oxides; the protoxide is black, or rather very deep blue, and is a compound of 3·5 iron and 1 oxygen, so that its atomic weight is 4·5. It nowhere occurs pure in the mineral kingdom, but it is found in combination with the peroxide of iron, constituting the well known ore called *magnetic iron ore.* The peroxide of iron is red, and is composed of 3·5 iron and 1·5 oxygen, so that its atomic weight is 5. It occurs in the mineral kingdom in a pure state, and likewise in combination with water, constituting various species, formerly confounded under the name of *hematite.*

Magnetic iron ore, which is a compound of protoxide and peroxide of iron, requires, to render it soluble in muriatic acid, to be previously fused with thrice its weight of anhydrous carbonate of soda. If we digest the fused mass in water till every thing soluble is taken up, the iron ore will remain in a state fit for solution in muriatic acid. To the solution add a little nitric acid, and digest for some time, in order to peroxidize the iron. Concentrate the solution nearly, but not quite, to dryness, to drive off as much of the excess of acid as possible. Then dilute with water, neutralize with ammonia, and precipitate the peroxide of iron by benzoate of ammonia. The precipitate being collected, washed, dried, and ignited, gives the weight of peroxide of iron from the portion of ore analyzed. If the ore be pure nothing will remain in solution after the iron is thrown down.

Suppose that the weight of magnetic iron ore (after ignition) experimented upon is 29 grains, and that we obtain when we precipitate it by benzoate of ammonia 30 grains of peroxide. It is clear from the increase of weight that the iron during the digestion with nitric acid had combined with an additional dose of oxygen. Thirty grains of peroxide of iron are composed of

Iron, . . .	21
Oxygen, . . .	9
	30

Now, 21 iron is equivalent to 6 atoms, the atomic weight of iron being 3·5; and 9 being equivalent to 9 atoms of oxygen, it is obvious that in the peroxide of iron every atom of the metal is united to 1½ atoms oxygen. But in the ore the metal was combined with only 8 atoms oxygen, as the original weight was only 29. It is obvious that in the ore 4 atoms of iron were combined with 1½ atoms of oxygen, and two with 1 atom; or which is the same thing, the ore is a compound of 2 atoms peroxide of iron and 1 atom of protoxide, for protoxide of iron is a compound of 1 atom iron and 1 atom oxygen.

Fuchs has shown that carbonate of lime has the property of precipitating the peroxide of iron from its solution, but not the protoxide. Hence it may be employed to separate the two oxides from each other. Liebig has found that carbonate of magnesia answers better than carbonate of lime, because it forms a double salt with protoxide of iron, and thus prevents it from falling down when it absorbs oxygen.*

Specular iron ore is wholly composed of peroxide of iron. It requires, like the preceding mineral, to be fused with carbonate of soda, to render it soluble in muriatic acid. But when we precipitate the iron, wash it, dry it, and expose it to

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* Ann. de Chim. et de Phys. xlviii. 290.

a red heat, no increase of weight takes place. Frequently this ore of iron is mixed with variable quantities of earthy matter. The analysis of such impure specimens is to be conducted precisely in the way described in the early part of this work, when the method of analyzing stony bodies was detailed.

The analysis of *manganesian iron ore* and *Franklinite* are conducted precisely on the same principles. The ore is rendered soluble in muriatic acid by fusing it with carbonate of soda. The water in the mineral is determined, and the silica separated by the rules already laid down. The iron (which is in the state of peroxide) is thrown down by benzoate of ammonia, and the manganese by chloride of lime saturated with chlorine, or at least containing no excess of lime. Six grains of this precipitate, which is red, after ignition is equivavalent to 4½ grains of protoxide of manganese.

After the separation of the iron and manganese nothing remains but the zinc, which is thrown down from the solution raised to the boiling temperature by the addition of carbonate of soda.

The *hydrous peroxide of iron*, or *hematites*, as they were formerly called by mineralogists, are analyzed in the same way, taking care in the first place, to determine the quantity of water, by the methods already explained.

Sect. 2. *Oxides of Manganese.*

Manganese never occurs in the mineral kingdom except in the state of oxide. The protoxide is only met with when the mineral consists of a salt; the sesquioxide and the binoxide occur both in a separate state, and variously united with each other, and with water. Some of these ores of manganese contain also barytes, in a state of chemical combination with the deutoxide of manganese, which appears to act the part of an acid. Nearly the same method of analysis is to be applied to them all.

100 grains, or (better) 200 grains of the ore broken into small fragments, are put into a small green glass or porcelain retort, to the beak of which is luted a glass tube, the internal cavity of which is about half an inch in diameter, and the length of the tube is about 12 inches. This tube is filled with fragments of fused chloride of calcium, kept in their place by a little amianthus or cotton inserted into the two extremities of the tube. The retort, with its contents, and likewise this glass tube, must be previously weighed. A strong red heat

is now applied to the retort, and it is kept in this state of ignition for about an hour. The retort, with its contents, including the tube filled with chloride of calcium, are now weighed. The diminution of weight indicates the oxygen gas which has been driven off from the manganese ore. The tube with the chloride of calcium being now weighed, the increase of weight indicates the water expelled from the ore.

Another portion of the ore is to be digested in muriatic acid till complete solution takes place. The solution being evaporated to dryness, and re-dissolved in water acidulated with muriatic acid, leaves the silica, which is collected and estimated in the usual manner. The solution thus freed from silica, is tested for iron and for barytes. Should iron be found, it must be peroxidized and thrown down by benzoate of ammonia. Should barytes be present, (which is a pretty common occurrence,) it may be thrown down by sulphate of soda or sulphate of ammonia, or even by sulphuric acid. The sulphate of barytes is to be washed, dried, ignited, and weighed. From it we easily deduce the quantity of barytes contained in the ore under examination.

The manganese may be precipitated by caustic ammonia, washed, dried, and ignited. It is in the state of red oxide, every 4·833 grains of which are equivalent to 5 grains of sesquioxide, and 4·5 grains of protoxide.

On comparing the weight of the manganese extracted with that of the ore examined, making allowance for the water, silica, and barytes, obtained, it is easy to see in what state of oxidation the manganese existed. For example, if the oxygen evolved when added to the red oxide obtained, will just convert the whole into sesquioxide, it is obvious, that in the ore the manganese was in the state of sesquioxide. If the red oxide and oxygen together, convert the manganese into deutoxide, then deutoxide is the state of oxidation of the manganese in the ore. Most frequently the manganese is not wholly in the state of sesquioxide nor of deutoxide, but intermediate between protoxide and sesquioxide, or between sesquioxide and deutoxide. The quantity of red oxide obtained and of oxygen evolved, is always sufficient to enable us to determine the exact state of the oxidizement of the manganese, remembering that the atomic weights of these bodies are as follows:—

Manganese, . . .	3·5
Protoxide, . . .	4·5

Sesquioxide, . . .	5
Red oxide, . . .	4·833
Deutoxide, . . .	5·5

When oxide of manganese and oxide of zinc occur together, as they do in red zinc, we dissolve the mixture in muriatic acid. The solution may be divided into two equal portions. From the one we precipitate the oxide of manganese by means of chloride of lime, and from the other the oxides of zinc and manganese together, by heat and carbonate of soda.* The precipitate being washed, dried, and strongly ignited, is a mixture of oxide of zinc and red oxide of manganese. The knowledge of the quantity of manganese precipitated from one half of the liquid by means of chloride of lime, will enable us to deduce the weight of zinc in the second precipitate. This being deducted from the original weight of the ore, (supposing nothing else present) gives the weight of the oxide of manganese. And as we know how much manganese exists in the ore, we can easily infer the state of its oxidizement.

Sect. 3. *Oxides of Lead.*

The protoxide of lead and also the sesquioxide, have been met with in the mineral kingdom. Should these minerals, or at least, the first of them, contain carbonic acid, the quantity may be determined by putting 100 or 200 grains of the ore into a small porcelain retort, to which a tube with chloride of calcium is luted. A red heat will drive off the carbonic acid, and the diminution of weight sustained by the retort and tube, gives the weight of carbonic acid driven off. The increase in the weight of the tube with chloride of calcium gives the quantity of water in the ore.†

Another portion of the ore may be reduced to a fine powder, and digested with potash or soda ley. The oxide of lead will be dissolved. What remains is impurity, consisting usu-

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* When oxides of iron, and manganese, and magnesia, occur together, they may be separated by the following method first suggested by Stromeyer: Let the iron be peroxidized. Throw it down by means of bicarbonate of potash. Render the residual liquid acid, dilute it, and pass a current of chlorine through it, then add bicarbonate of potash. The manganese falls in the state of binoxide. Care must be taken to add the bicarbonate slowly as long as a precipitate falls. The magnesia may now be precipitated by phosphate of soda and caustic ammonia. See Poggendorff's Annalen, xi. 170.

† When the red oxide of lead is treated in this way, the loss of weight is owing to the evolution of oxygen gas, not of carbonic acid gas.

ally of oxide of iron, silica, lime, and perhaps alumina. This residue is to be analyzed by the rules already laid down in the first division of this treatise. The alkaline solution is neutralized by nitric acid, and the oxide of lead thrown down by sulphate of ammonia. The sulphate of lead, washed, dried, and ignited, is to be weighed. If we multiply the weight by 0·737, the product will indicate the weight of protoxide of lead which it contains. Knowing the weight of protoxide of lead, it is easy to deduce that of sesquioxide, for every 14 grains of protoxide are equivalent to 14½ grains of sesquioxide of lead.

The sulphate of ammonia does not throw down the whole of the lead: a little escapes and still remains in the liquid. If we evaporate the solution to dryness and ignite the residue, and then dissolve it in water, a portion of this lead will be separated in the state of sulphate, but not the whole. The best way therefore, is to throw down this residue by means of sulphuretted hydrogen gas. The precipitate when washed, dried, and ignited, is sulphuret of lead, every 15 grains of which is equivalent to 14 grains of protoxide, or 14·5 grains of sesquioxide of lead.

Sect. 4. *Oxide of Tin.*

The only oxide of tin found native is the peroxide, constituting an exceedingly hard heavy ore, having the diamond lustre, and a brown or black colour. It is quite insoluble in acids, even when reduced to a very fine powder. Nor does it become soluble though fused with carbonate of soda. But if we mix it with five times its weight of caustic potash or soda, and ignite the mixture in a silver crucible furnished with a close cover, for half an hour, we obtain a mass which has usually a green colour, and which may be dissolved in muriatic acid. If the tinstone was pure, the solution is generally complete.

Through the muriatic solution rendered as neutral as possible by concentration and subsequent dilution with water, a current of sulphuretted hydrogen is passed as long as any precipitate falls. The yellow-coloured precipitate is collected on a filter, washed, and digested in aqua regia till it is completely dissolved. The oxide of tin is now thrown down by caustic ammonia, washed, heated to redness, and weighed. Ammonia does not throw down the whole of the oxide of tin. But if we add succinate of ammonia, and leave the mixture for some time at rest, the whole peroxide of tin remaining in the liquid is precipitated. It may be ignited and weighed, and the weight added to that of the peroxide previously obtained.

The liquid from which the peroxide of tin has been precipitated by sulphuretted hydrogen, is now to be examined. Let a little nitric acid be added to it, and let the whole be digested for some time to peroxidize the iron which it always contains. Let the liquid be now neutralized and precipitated by benzoate of ammonia. Collect the precipitate, wash it, ignite it, and weigh it. Let it then be digested in muriatic acid; if it dissolve completely, it is pure peroxide of iron. If it leave an insoluble residue, which is often the case, subtract the weight of this residue from that of the whole ignited precipitate; the remainder is the weight of peroxide of iron. The insoluble residue is usually peroxide of tin. This is easily determined by mixing it with some carbonate of soda and borax, and fusing it before the blowpipe on charcoal. If it be oxide of tin, that metal will be reduced and a globule of tin obtained.

The liquid freed from iron and tin may still contain oxide of manganese. Add to it a quantity of sulphohydrate of ammonia, and set it aside in a phial furnished with a ground stopper. If manganese be present, a reddish or yellowish precipitate gradually falls. Collect this precipitate, wash it, and dissolve it in muriatic acid. Raise the solution to the boiling temperature, and throw down the oxide of manganese by carbonate of soda. The precipitate collected, washed, dried, and strongly ignited, is red oxide of manganese, every 4·833 grains of which are equivalent to 4·5 grains of protoxide, and 5 grains of sesquioxide.

Sect. 5. *Oxide of Bismuth.*

Bismuth is found much more abundantly in the metallic state than in any other; yet the oxide of bismuth has been met with in the mineral kingdom, sometimes isolated, or nearly so, and sometimes united to carbonic acid.

Oxide of bismuth must be dissolved in nitric acid. After rendering the solution as neutral as we can by concentration, we add a quantity of acetic acid, and then dilute with water. A current of sulphuretted hydrogen gas is then passed through, till the whole bismuth is precipitated in the state of sulphuret. The sulphuret is dissolved in nitric acid, and the oxide of bismuth thrown down by carbonate of ammonia. The precipitate washed, dried, and ignited, is pure oxide of bismuth.

The liquid from which the bismuth has been precipitated by sulphuretted hydrogen, is to be digested with some nitric acid, after having driven off the excess of sulphuretted hydrogen. It is then to be neutralized and thrown down by benzoate of ammonia. The precipitate after ignition gives the quantity of peroxide of iron contained in the ore.

These are the only substances said to exist in oxide of bismuth. Should it leave an earthy residue it may be analyzed by the rules already laid down.

Sect. 6. *Oxides of Copper.*

Both the oxides of copper occur native. The *red* crystallized, and in a state of great purity; the *black* usually mixed with oxide of iron. The analysis of both is exceedingly easy. The red oxide may be digested in muriatic acid, and to the solution nitric acid may be added till it has assumed the usual green colour which characterizes the solution of black oxide of copper in muriatic acid. We may then test the solution for iron, or any other impurity which may be suspected, and if nothing be found we neutralize the solution and throw down the oxide of copper with caustic potash. When this oxide is weighed after ignition, every 5 grains of it are equivalent to 4½ grains of red oxide of copper. Or the red oxide is equivalent to nine-tenths of the black oxide obtained.

The analysis of the black oxide is to be conducted in the same way. Only the iron must be precipitated by benzoate of ammonia. And should alumina, silica, or lime, be present, as may occasionally be the case, they are to be separated and analyzed in the usual way.

Sect. 7. *Oxides of Arsenic.*

Both arsenious and arsenic acid occur in the mineral kingdom, sometimes in a separate state, but more frequently united with bases. Our business here is only with these bodies when in a separate state.

Arsenious acid may be dissolved in aqua regia, and precipitated in the state of sulphuret by a current of sulphuretted hydrogen gas. The precipitate is to be washed upon a filter, and dried in a gentle heat. This sulphuret is analogous to arsenious acid, every 7¾ grains of it being equivalent to 6¼ grains of arsenious acid. But it is apt to contain an excess of sulphur, in consequence of the decomposition of some of the sulphuretted hydrogen. On that account it is better to determine its composition by analysis. Put a portion of it into a flask, and digest it cautiously with aqua regia till the sulphur collects into lumps, separate the sulphur, wash it, dry it, and weigh it. The liquid contains a portion of the sulphur converted into sulphuric acid. Throw it down by chloride of barium, and determine its weight. From this the weight of the sulphur which it contains is easily deduced. Subtract the weight of the sulphur from that of the sulphuret analyzed, the remainder gives the weight of the arsenic. And every 4·75 grains of metallic arsenic are equivalent to 6¼ grains of arsenious acid.

Arsenic acid may be precipitated in the same way by sulphuretted hydrogen gas. But the process is a good deal more tedious. Every 9·75 grains of the precipitated sulphuret are equivalent to 7¼ grains of arsenic acid. But it is better to determine the weight of sulphur contained in this sulphuret, from which the weight of the arsenic is deduced as before. And every 4·75 grains of metallic arsenic are equivalent to 7¼ grains of arsenic acid.

Berthier has proposed another way of determining the quantity of arsenic acid when in solution, which may be frequently practised with advantage, and therefore deserves to be described here:—A quantity of iron (as pure as possible) is dissolved in nitric acid, and the solution is mixed with the liquid containing the arsenic acid. The process succeeds very well though the solution contains nitric acid, muriatic acid, or sulphuric acid. It may contain also fixed alkalies, or indeed any base which does not form an insoluble salt with arsenic acid, sulphuric acid, or muriatic acid, and which is not precipitable by ammonia, either by itself or in combination with any of the acids present in the liquid.

To the mixture ammonia is added in excess: the peroxide of iron falls down in combination with the arsenic acid. It is better that a considerable excess of iron should be present, so as to form a subsalt, for the neutral arseniated peroxide of iron is very gelatinous and difficult to wash. The precipitate is to be washed on a filter, dried, and very cautiously heated to ignition. If it were very rapidly ignited, and ammonia be present in it, (as is often the case, the precipitate being an ammonia-subsesquiarseniate of iron,) the ammonia would act upon the arsenic acid, and convert it into arsenious acid, which would be driven off by the heat. The precipitate, after strong ignition, is to be weighed. Knowing the weight of iron employed, we have the quantity of peroxide of iron present. This being deducted from the weight of the precipitate, the remainder is the amount of arsenic acid.

The only objection to this method of Berthier is the impossibility of obtaining iron perfectly pure. We cannot err very much if we allow half a per cent. of impurity, and reckon only 99·5 grains for every 100 grains of iron that we employ. According to this mode of estimating, 100 grains of iron yield 142·143 grains of peroxide. Knowing the weight of peroxide, it is easy to deduce that of the arsenic acid.

When arsenious, or arsenic, acid is in a solution with bodies not precipitable by sulphuretted hydrogen, we can easily throw down these acids by means of a current of that gas. We begin by rendering the solution slightly acid, and then the current of gas is continued till the liquid is saturated. We then expose it to a gentle heat till the smell of sulphuretted hydrogen vanishes. The precipitated sulphuret is collected on the filter, and the quantity of arsenic which it contains estimated in the way already explained. In this way these acids may be separated from *potash*, *soda*, *lithia*, *barytes*, *strontian*, *lime*, *magnesia*, *alumina*, and *the other earths*, *manganese*, *iron*, *zinc*, *cobalt*, *nickel*, *uranium*, *titanium*, and *chromium*.

When the bases with which these acids are combined are precipitated by sulphuretted hydrogen gas, we must employ sulphohydrate of ammonia to separate them. We must render the solution ammoniacal, and then add an excess of sulphohydrate of ammonia. The whole is put into a well closed flask, and digested for some time in a gentle heat. The bases are thrown down in the state of sulphurets, while the arsenic is held in solution. We filter to separate the precipitate, and to the filtered liquid add an excess of muriatic acid, and digest till the smell of sulphuretted hydrogen is dissipated. The sulphuret of arsenic precipitates, and is collected and analyzed in the way already explained.

In this way arsenious and arsenic acid may be separated from *cadmium*, *lead*, *bismuth*, *copper*, *mercury*, and *silver*. The same method may also be followed, if we think proper, to separate these acids from oxides of manganese, iron, zinc, cobalt, &c. For all these oxides are converted into sulphurets, and precipitated by sulphohydrate of ammonia. Nor is there any reason why it may not be employed to separate the same acids from alkalies and earthy bodies.

We cannot separate arsenic acid from metallic oxides by precipitating these oxides by means of caustic potash or soda, because a portion of the arsenic acid always falls down in combination with the oxide, and no excess of alkali, even assisted by long continued digestion, is capable of preventing this. The method therefore of analyzing arseniates of copper practised by Klaproth and Chenevix, could not be exact.

Sect. 8. *Oxide of Antimony.*

The protoxide of antimony is found in the mineral kingdom, though it is rather a scarce mineral. It may be easily recognised by the characters already given in a former part of this treatise, especially by the action of the blowpipe. When we wish to analyze it, the best method of proceeding is to dissolve it in muriatic acid, and throw it down by a current of sulphuretted hydrogen. The solution after saturation is left in a warm place till the smell of sulphuretted hydrogen vanishes. For the whole sulphuret of antimony does not fall as long as there is any sulphuretted hydrogen in the liquid. We then collect the sulphuret of antimony on a weighed filter, wash it well, and dry it in a gentle heat. After the sulphuret is dry, we must take a small quantity of it and digest it in concentrated muriatic acid. If it dissolve completely with the evolution of sulphuretted hydrogen gas, then the sulphuret is a compound of 3 sulphur and 8 antimony, so that every 11 grains of it are equivalent to 8 grains of antimony, or $9\frac{1}{2}$ grains of protoxide of antimony. But if it leaves a portion of sulphur undissolved, we must infer that it is a mixture of various sulphurets, and must subject it to analysis, in order to determine its composition.

For this purpose we may put a quantity of the sulphuret into a glass spherule blown in the middle of a tube. To one extremity is attached an apparatus for generating hydrogen gas, and a tube filled with dry chloride of calcium, through which it must pass. As soon as the apparatus is filled with hydrogen gas, heat is applied to the sulphuret in the spherule. The sulphur is converted into sulphuretted hydrogen gas, and gradually dissipated, while the antimony is reduced. We weigh the antimony, and subtracting the weight from the quantity of sulphuret subjected to analysis, we have the weight of the sulphur, and thus know the composition of the sulphuret of antimony.

Or we put a determined portion of our sulphuret of antimony into a flask, and pour upon it very cautiously fuming nitric acid by a small quantity at a time. When a sufficient quantity of nitric acid has been added, we pour into the flask concentrated muriatic acid, and digest till the whole is dissolved. To this solution add tartaric acid to prevent the precipitation of the antimony when it is diluted, then throw down the sulphuric acid by chloride of barium. From the weight of the sulphate of barytes obtained, we deduce that of the sulphuric acid, which gives us that of the sulphur. The weight of the sulphur subtracted from that of the sulphuret employed gives us that of the antimony; and thus the composition of the sulphuret is known.

Sect. 9. *Oxide of Chromium.*

I am not certain that the oxide of chromium has hitherto been met with in the mineral kingdom in an isolated state, though that such a mineral species may be met with hereafter is not unlikely. But this oxide occurs as an essential constituent of *chromeiron ore*, a mineral of great importance, because it is from it that all the chromate of potash, so much employed in calico printing is procured. Its essential constituents are green oxide of chromium, peroxide of iron, and alumina.

To analyze it, the best way is to reduce it to powder, and to mix it with thrice its weight of caustic potash and saltpetre and fuse the mixture in a silver crucible. By this fusion the oxide of chromium is converted into chromic acid. Digest the fused mass in water till every thing soluble is taken up. The solution has a yellow colour, and is a combination of chromic acid with a great excess of potash. Saturate the alkali with acetic acid, and throw down the chromic acid by acetate of lead. The precipitate, when washed, dried, and ignited, is composed of 14 parts of lead, and 6·5 of chromic acid. Hence every 20·5 grains of the ignited precipitate contain 6·5 grains of chromic acid equivalent to 5 grains of green oxide.

Before throwing down the chromic acid it is better to add a slight excess of carbonate of ammonia, which throws down the alumina. When washed, dried, and ignited, it is to be weighed, and then dissolved in muriatic acid to separate a little silica, which is usually present.

The portion of the matter which does not dissolve in water consists chiefly of peroxide of iron. It is to be dissolved in muriatic acid, and after being neutralized the peroxide of iron is thrown down by benzoate of ammonia. Being washed, dried, and ignited, it consists of nearly pure peroxide of iron. When re-dissolved in muriatic acid it sometimes leaves a little silica.

The liquid thus freed from iron may be tested by carbonate of ammonia to see whether it contains any other substance. I have always found that when it is diluted with water it lets fall a small quantity of white matter, seemingly a salt, but existing in such minute quantity that its nature could not be determined.

Instead of throwing down the chromic acid by means of acetate of lead, we may reduce it again to the state of green oxide. The method of proceeding is this:—We cautiously add muriatic acid to the potash solution of chromic acid till there is an excess of acid, and boil the liquid in a flask till the chromic acid is reduced to green oxide. We then add ammonia, which throws down the oxide. We collect it on a filter, wash it, dry it, expose it to a red heat, and determine its weight.

Sect. 10. *Oxide of Uranium.*

The only mineral containing oxide of uranium in an uncombined state is pitchblende, which is rather a mixture than a chemical compound. For not merely the proportions, but even the constituents vary in different specimens, as has been explained, when describing the ore in the first part of this work.

Uranium in the metallic state has only been obtained as a brown powder destitute of the metallic lustre. It forms two oxides. The protoxide is of a dingy grey colour, and the peroxide, or uranic acid, has probably a yellow colour, at least all the compounds which it forms are yellow. The protoxide after ignition is hardly soluble in muriatic acid, but it dissolves easily in nitric acid, and in concentrated sulphuric acid, when assisted by heat. The sulphated protoxide of uranium exhibits the following characters to reagents:—

(1.) Potash throws down a bulky brown precipitate, not soluble in an excess of the precipitant.

(2.) Ammonia throws down a dark brown precipitate, also insoluble in an excess of ammonia. The upper surface of this precipitate, after a considerable interval, becomes yellow, being converted into peroxide.

(3.) Carbonate of potash throws down a dingy green precipitate, soluble in a great excess of the carbonate. Bicarbonate of potash and carbonate of ammonia act in the same manner, only the precipitate is more readily dissolved than when carbonate of potash is the precipitant.

(4.) Phosphate of soda, when the solution does not contain too much acid, throws down a dirty greenish-white precipitate.

(5.) Oxalic acid throws down a dirty greenish-yellow precipitate, even when the solution contains a considerable excess of acid.

(6.) Prussiate of potash throws down a reddish-brown precipitate.

(7.) Sulphuretted hydrogen occasions no precipitate, but sulphohydrate of ammonia throws down a black precipitate, provided the solution does not contain too much free acid. The precipitate is insoluble in an excess of sulphohydrate of ammonia.

When the peroxide of uranium is exposed to a red heat it is converted into protoxide, and assumes a dark green colour. When peroxide of uranium is thrown down by potash or soda the precipitate contains a quantity of the alkali, and assumes an orange-yellow colour when heated to redness.

The solution of peroxide of uranium in nitric acid has a greenish-yellow colour. The action of reagents upon this salt is as follows:—

(1.) Potash throws down a yellow precipitate insoluble in an excess of the precipitant. Ammonia acts in the same way.

(2.) Carbonate of potash throws down a yellow precipitate, soluble in an excess of the carbonate. Bicarbonate of potash and carbonate of ammonia act in the same way. When these solutions, with excess of alkaline carbonates, are kept, a yellow precipitate falls.

(3.) Phosphate of soda throws down a white precipitate with a tint of yellow, provided the solution does not contain too large an excess of acid.

(4.) Prussiate of potash throws down a reddish-brown precipitate, very characteristic of uranium.

(5.) Sulphuretted hydrogen occasions no precipitate; sulphohydrate of ammonia throws down a brown precipitate, provided there be no considerable excess of acid.

(6.) When heated with biphosphate of soda before the blowpipe the globule assumes in the outer flame a yellowish colour, inclining to green. On cooling the colour changes entirely to green. When the bead is melted by the interior flame the colour is green; when fused with borax the colours are nearly the same.

CHAP. IX.

ANALYSIS OF SULPHURETS AND SULPHUR SALTS.

SULPHUR occurs in the mineral kingdom combined with iron, manganese, nickel, cobalt, molybdenum, lead, tin, zinc, bismuth, copper, mercury, and silver, and with some of these metals in more than one proportion. It constitutes also one of the constituents of the sulphur salts of iron, of lead, of copper, and of silver. We must point out the methods of analysis to be followed with all these numerous compounds.

Sect. 1. *Sulphurets of Iron.*

There are three combinations of iron and sulphur which are found in the mineral kingdom, namely, *magnetic pyrites*, *bisulphuret of iron*, or *common pyrites*, and *radiated pyrites*, but the method of analyzing them is the same for all.

The mineral to be subjected to analysis must be reduced to powder and put into a glass flask; into the mouth of this flask a funnel is put, and strong fuming nitric acid is added by little at a time, waiting always till the action of the first portion is at an end before an additional portion is added. It is best to place the flask upon hot sand to promote the action. When this process is rightly followed the whole sulphur is converted into sulphuric acid, while at the same time the iron is peroxidized. We then dilute the whole with water, and, if necessary, add a little muriatic acid to dissolve the peroxide of iron completely. The peroxide of iron is then precipitated by ammonia, washed, dried, ignited, and weighed. Every 5 grains of it are equivalent to 3·5 grains of iron.

The liquid thus freed from iron is neutralized by muriatic acid, and the sulphuric acid which it contains is thrown down by chloride of barium. We collect the sulphate of barytes on a filter, and wash it carefully with boiling water. The washing is a tedious process. I am in the habit of acidulating the water with a little nitric acid, which I consider as facilitating the washing. From the weight of the ignited sulphate of barytes it is easy to determine that of the sulphur by the methods already explained.

It is not very often that the sulphurets of iron are analyzed by means of fuming nitric acid. Dilute nitric acid is much more frequently used. When we digest sulphuret of iron in dilute nitric acid, the iron is peroxidized and dissolved long before the sulphur is all acidified. When the sulphur has concreted into lumps, and assumed its natural greenish-yellow colour, we collect it on a weighed filter, wash it, and dry it in a gentle heat. We then collect as much of it as possible into a porcelain crucible, and burn it all away. A small residue of oxide of iron usually remains, amounting only to a fraction of a grain. We determine its weight, and then dissolve it in muriatic acid. In general a minute quantity of silica is left, which we determine and subtract from the weight of the oxide. The muriatic solution must be tested by chloride of barium, to ascertain whether any sulphuric acid be present. If there is, we determine its amount, subtract it from the oxide, and add the sulphur which it contains to the weight of the sulphur previously found, less the weight of the residual oxide.

The liquid thus freed from sulphur is neutralized, and the peroxide of iron thrown down by ammonia. After washing, drying, and ignition, the amount of iron is determined as before. We then throw down the sulphuric acid by chloride of barium, and estimate the sulphur as before.

Magnetic pyrites is soluble in muriatic acid, and during the solution sulphuretted hydrogen escapes. If the pyrites be pure no sulphur is precipitated, and no sulphuric acid is ever found in the solution. This shows clearly that magnetic pyrites is a compound of 1 atom of iron and 1 atom of sulphur.

Common pyrites is insoluble in muriatic acid; but if we expose it to a red heat half the sulphur is driven off, and the residue, reduced to the state of magnetic pyrites, is soluble in muriatic acid without a residue.

The analysis of radiated pyrites is to be conducted precisely in the same way as that of common pyrites. No difference between the constitution of the two species has been discovered.

Native magnetic pyrites is combined usually with a variable quantity of common pyrites: hence, when digested in muriatic acid it is never completely soluble; and if the iron dissolve completely, a little sulphur will be left behind, showing that the atoms of sulphur somewhat exceed those of iron.

Sect. 2. *Sulphuret of Manganese.*

Sulphuret of manganese may be analyzed exactly in the same way as sulphuret of iron. The manganese is usually obtained in the state of red oxide, every 4·833 grains of which are equivalent to 3·5 grains of metallic manganese.

Arfvedson employed the following method to analyze this mineral:—He roasted the sulphuret, previously reduced to powder, till it ceased to undergo any alteration in weight. This process is tedious. What remained was pure red oxide of manganese,* every 4·833 grains of which are equivalent to 3·5 grains of metallic manganese. Knowing the weight of the specimen subjected to analysis, and of the manganese which it contained, it was easy to deduce that of the sulphur.†

Sect. 3. *Sulphuret of Nickel.*

The sulphuret of nickel may be analyzed in the same way as the preceding sulphurets; or we may digest it in aqua regia till every thing is dissolved but a little sulphur, which is to be separated and estimated in the way already described when treating of the sulphurets of iron. The solution is to be precipitated by chloride of barium, and from the weight of the sulphate of barytes that of the acidified sulphur determined. The oxide of nickel is now to be precipitated by caustic potash or soda, and its weight estimated after ignition. Every 4·25 grains of it are equivalent to 3·25 grains of metallic nickel.

Sect. 4. *Sulphuret of Cobalt.*

The only specimens of sulphuret of cobalt hitherto examined by chemists contained, besides sulphur and cobalt, some copper and some iron. Such a sulphuret may be analyzed by the following method:—Digest it in dilute nitric acid till every thing is dissolved except a little sulphur. Towards the end of the digestion the solution is facilitated by adding a little muriatic acid. Separate the sulphur, and treat it in the way already explained.

Through the solution pass a current of sulphuretted hydrogen till every thing precipitable by that reagent is thrown

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* It contained merely a trace of iron.

† Kong. Vet. Acad. Handl., 1822, p. 435.

down. By this process we separate the copper in the state of sulphuret. This sulphuret is dissolved in a boiling heat in nitric acid, except a little sulphur, which is separated by the filter. The nitric acid solution is then mixed with an excess of caustic potash or soda, and the black oxide of copper separated. After ignition every 5 grains of it are equivalent to 4 grains of metallic copper.

The red cobalt solution thus freed from copper is to be neutralized, and the peroxide of iron which it contains is to be thrown down by benzoate of ammonia. The benzoate being ignited leaves peroxide of iron, every 5 grains of which are equivalent to 3·5 grains of metallic iron. Finally, the oxide of cobalt must be thrown down by caustic potash or soda. This oxide after ignition is composed of 3·25 cobalt and 1 oxygen, so that every 4·25 grains are equivalent to 3·25 grains of metallic cobalt.

Sect. 5. *Sulphuret of Molybdenum.*

The only combination of molybdenum and sulphur hitherto met with in the mineral kingdom is *molybdena*, or *disulphide of molybdenum.*

We cannot determine the quantity of sulphur in this mineral by roasting, because the molybdenum makes its escape during the process as well as the sulphur. The best way is to put the quantity to be subjected to analysis, reduced to as thin leaves as possible, into a retort, and to pour over it moderately strong nitric acid. This acid is to be distilled nearly to dryness, and a new portion of acid being poured on, we continue the process till the sulphuret has lost its appearance and is quite decomposed. We then (after driving off most of the acid) digest the residue in a sufficient quantity of caustic ammonia, to dissolve the whole. From this solution, muriatic acid throws down the molybdenum in the state of molybdic acid. Every 9 grains of this when washed, dried, and ignited, are equivalent to 6 grains of metallic molybdenum. From the liquid thus freed from molybdenum, we throw down the sulphuric acid by means of chloride of barium. The sulphate of barytes being weighed after ignition, it is easy from it to deduce the quantity of sulphur existing in the specimen subjected to analysis.

Should sulphuret of molybdenum contain fragments of quartz, as is sometimes the case, they remain undissolved when the matter in the retort is taken up by ammonia.

Sect. 6. *Sulphuret of Lead.*

The easiest method of determining the constituents of sulphuret of lead, is to reduce a quantity of it to powder, to put it into a flask, and digest it with fuming nitric acid added very cautiously, by a little at a time. By this treatment, the sulphuret is converted into sulphate of lead. Every 19 grains of ignited sulphate is equivalent to 15 grains of sulphuret of lead. Suppose in any process we obtain 38 grains of sulphate of lead, we say, 19 : 15 : : 38 : 30 = sulphuret of lead. If the quantity of sulphuret of lead be exactly equivalent to the 30 grains thus obtained by calculation, that is to say, if we employed just 30 grains of sulphuret of lead in our experiment, it follows that the galena examined was pure, and a compound of 1 atom sulphur and 1 atom lead. But if the quantity was either greater or less than 30, and if we be sure that we lost nothing during the process,* it is clear that the sulphuret contained something else than pure lead and sulphur.

When we wish to determine the quantity of sulphur combined with the lead exactly, we put a quantity of the galena in powder into a glass globule, to each side of which a glass tube is cemented. To one of these tubes is attached an apparatus for generating hydrogen, with a glass tube filled with fragments of chloride of calcium, through which the hydrogen passes. When the apparatus is filled with hydrogen gas, we apply the heat of a lamp to the galena, and continue the heat and the evolution of hydrogen gas till the whole sulphur is disengaged in the state of sulphuretted hydrogen gas. We then allow the apparatus to cool, and weighing the lead, we have by subtracting the weight from that of the original sulphuret, the quantity of sulphur with which the lead was combined.

Sect. 7. *Sulphuret of Tin.*

The sulphuret of tin is a rare ore, and hitherto has, so far as I know, been analyzed by Klaproth only. He found in it, besides sulphur and tin, copper and iron. His mode of analysis was this:

He digested the ore in aqua regia till the sulphur remained, being recognised by its yellow colour. The sulphur was separated, washed, dried, and weighed. It was then burnt

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* The sulphate of lead should be ignited in a covered crucible.

off. The residue was undecomposed ore, which was treated as before with aqua regia, and the sulphur burnt off. These processes were repeated till the ore was completely decomposed.

The liquid was mixed with chloride of barium, and the sulphate of barytes being washed, dried, and ignited, its weight gave the means of determining the quantity of sulphur that had been acidified. This added to the sulphur burnt off, gave the whole weight of sulphur contained in the portion of ore subjected to analysis.

The liquid thus freed from sulphuric acid, and afterwards from barytes, was concentrated and mixed with a great excess of caustic ammonia, which retained the copper in solution but threw down the tin and iron. The ammoniacal solution was saturated with sulphuric acid, and the copper being precipitated by an iron plate, was washed, dried, and weighed.

The mixed precipitate of oxides of tin and iron, was digested in a solution of caustic potash, which dissolved in a boiling heat the oxide of tin, but left the oxide of iron. The solution being filtered and saturated with muriatic acid, a plate of zinc threw down the tin, which was washed, dried, and weighed.

The iron was drenched in oil and heated to bring it to the state of black oxide. It was found all to be attracted by the magnet. From its weight, that of the iron contained in the ore was calculated.*

This method though ingenious, and though considerably better than the method at first followed by Klaproth, is not susceptible of any great degree of accuracy.

Sect. 8. *Sulphurets of Bismuth.*

There are two minerals containing sulphur and bismuth which have been met with in the mineral kingdom. The first, *bismuth glance*, or *sulphuret of bismuth*, and the second, *needle ore of bismuth*, a very complicated ore, which, besides bismuth and sulphur, contains also lead, copper, nickel, tellurium, and gold.

Sulphuret of bismuth is rather a scarce ore, and so far as I know, has been hitherto analyzed only by M. H. Rose. The analysis is very simple. The pounded ore is digested in a flask with concentrated nitric acid, till every thing is dissolved. Carbonate of ammonia throws down the oxide of bismuth. It

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* Beitrage, v. 228.

is washed, dried, ignited, and weighed. Every 10 grains of it are equivalent to 9 grains of metallic bismuth. The sulphuric acid is precipitated from the liquid (after it has been rendered neutral by muriatic acid) by means of chloride of barium. From the sulphate of barytes, the quantity of sulphur is determined in the way already explained.

Needle ore of bismuth was analyzed by John, as long ago as 1808. He dissolved it in nitric acid, and concentrated the solution to get rid of the excess of acid. Being now diluted with water, the oxide of bismuth was precipitated. It was washed, dried, and ignited, and from its weight, that of the metallic bismuth contained in the ore was deduced.

Sulphate of soda being poured into the blue liquid remaining, the lead was precipitated in the state of sulphate. When this sulphate is washed, dried, and ignited, if we multiply its weight by 0·684, the product will give the weight of metallic lead which it contains.

The residual liquid was precipitated by an excess of caustic potash. The precipitate was again re-dissolved in sulphuric acid, and the copper thrown down by a bar of iron.

The ferruginous solution from which the copper had been thrown down, was mixed with an excess of carbonate of ammonia, and the precipitate was washed repeatedly with fresh doses of ammonia. A blue coloured solution was obtained, which was concentrated, neutralized with sulphuric acid, and a plate of iron was put into it. Some black flocks were precipitated which possessed the characters of copper. The liquid was now precipitated by carbonate of potash. The precipitate being digested in ammonia, left a little oxide of iron. The portion dissolved was considered to be oxide of nickel, because it dissolved in ammonia with a blue colour, gave a green precipitate with prussiate of soda, and a yellow with infusion of nut galls.

What remained undissolved by the nitric acid, after being dried and weighed, was heated, sulphur burnt off, and its weight was determined. The residue was treated with nitromuriatic acid, which dissolved it, with the exception of some quartz grains. The solution being concentrated to get rid of the excess of acid, and then diluted with water, yielded a precipitate of oxide of bismuth. The liquid separated from this precipitate had a yellow colour, and nitrate of mercury threw down from it a small quantity of gold.*

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* Gehlen's Journal (second series), v. 230.

This mode of analysis was scarcely capable of giving correct results; but it will be better to delay giving any account of the mode of analyzing these complicated ores till we come to treat of the sulphur salts, because one general process may be given which will apply to them all, and thus considerably shorten the details.

Sect. 9. *Sulphuret of Copper.*

The only simple combination of copper and sulphur found in the mineral kingdom, is *glance copper*, or *disulphuret of copper*. Besides copper and sulphur it contains a little iron, probably in the state of bisulphuret.

The portion of this disulphuret intended to be analyzed is digested with pretty strong nitric acid, or aqua regia on the sand bath till the whole is dissolved, or till nothing remains but sulphur concreted in lumps. This sulphur is separated, washed, dried, and burnt off after being weighed, and any residue is to be digested anew in nitric acid, or aqua regia, till the whole be dissolved. The sulphuric acid is thrown down from the liquid by chloride of barium, and the amount of the sulphur which it contains determined as already explained.

From the liquid (previously deprived of any barytes that may have been added in excess) we throw down the peroxide of iron by benzoate of ammonia, taking care to neutralize it exactly before adding the benzoate.

The copper now only remains which may be thrown down in the state of black oxide by caustic potash or soda.

Sec. 10. *Sulphuret of Zinc.*

There are two ores of zinc which contain sulphur. These are *blende* or *sulphuret of zinc*, very seldom free from iron, and *Voltzine* or *oxysulphuret of zinc*, containing sulphuret of zinc, oxide of zinc, and oxide of iron.

The mode of analyzing blende is precisely the same as that of disulphuret of copper, only that the oxide of zinc must be thrown down by carbonate of soda at a boiling temperature.

Nor is it necessary to point out any particular rules for the analysis of Voltzine, which may obviously be conducted precisely in the same way.

The animal matter which this mineral contains is soluble in weak muriatic acid. We must therefore begin the analysis by digesting the ore in weak muriatic acid. From this solution the animal matter is thrown down in the state of a white powder by diluting it with water. When this matter is heated it melts. If we increase the heat it swells up and leaves a charry matter, which when burnt leaves oxide of zinc. Probably this oxide was thrown down in combination with the animal matter.

Sec. 11. *Sulphuret of Mercury.*

The only combination of sulphur and mercury met with in the mineral kingdom is *cinnabar*, which is a simple sulphuret.

It must be digested in a flask upon the sand bath, with pretty strong aqua regia, for nitric acid is not capable of decomposing it. If the digestion be continued long enough the whole sulphur is acidified. The sulphuric acid is thrown down by chloride of barium, and the quantity of sulphur determined in the way already explained.

We now pass a current of sulphuretted hydrogen gas through the solution, till the whole mercury is precipitated in the state of sulphuret. This sulphuret is collected and washed on a weighed filter, and then dried in a gentle heat. Put this sulphuret into a flask, and pour over it a little muriatic acid. Then pass over it a current of chlorine till the mercury is changed into chloride, and the sulphur disengaged. Filter off the chloride of mercury, after all the free chlorine has been dissipated, and mix the liquid with a solution of protochloride of tin. The mercury is thrown down in the metallic state. It is to be washed, dried, and weighed.

Sec. 12. *Sulphurets of Silver.*

There are three ores composed of silver and sulphur. *Silver glance* or *common sulphuret* contains when pure nothing but silver and sulphur. But *flexible sulphuret* and *Sternbergite* contain also metallic iron.

Sulphuret of silver is to be digested in pure nitric acid till the sulphur appears in clots, and of its usual colour. We then filter off the liquid, throw down the sulphuric acid formed by means of nitrate of barytes, and estimate the sulphur as already explained.

The liquid thus freed from sulphuric acid is mixed with muriatic acid, or sal ammoniac. The silver falls down in the state of chloride. It is to be collected, washed, dried, fused, and weighed. Every 18·25 grains of it are equivalent to 13·75 grains of metallic silver.

If the sulphuret analyzed contained iron, it will remain in solution after the separation of the sulphur and silver. If we are sure that nothing is present but peroxide of iron, we may throw it down by caustic ammonia. Should any thing else be suspected we precipitate the iron by benzoate of ammonia, and then test the residual liquid to determine whether any other substance be present.

Sec. 13. *The Sulphur Salts.*

The mode of analyzing all the combinations of sulphur and the metals has been explained in the preceding sections, excepting the compounds which it forms with arsenic and antimony. Now these combinations constitute sulphur acids, which have the property of combining with other metallic sulphurets as bases, and thus of forming what are called *sulphur salts.* The analysis of these sulphur salts is attended with peculiar difficulties, which were first effectually overcome by M. H. Rose; though Bonsdorff, Arfvedson, and above all Berzelius had previously pointed out what may be called the theory of the processes.

The sulphur salts hitherto met with in the mineral kingdom, and whose analysis will occupy our attention in this section, are the following:—

I. Sulphur salts of iron.
   1. *Arsenical pyrites;* composed of sulphur, arsenic, and iron.
   2. *Berthierite;* composed of the same constituents, with traces of zinc and some iron pyrites.

II. Sulphur salts of nickel.
   1. *Nickel glance;* composed of sulphur, arsenic, and nickel, with a little iron and trace of cobalt.
   2. *Sulpho-antimonite of nickel;* composed of sulphur, antimony, and nickel.

III. Sulphur salts of cobalt.
   1. *Cobalt glance;* composed of sulphur, arsenic, and cobalt, with a little iron.

IV. Sulphur salts of lead.
   1. *Zinkenite;* composed of sulphur, antimony, and lead, with a little copper.
   2. *Plagionite;* composed of sulphur, antimony, and lead.
   3. *Jamesonite;* composed of sulphur, antimony, and lead, with some iron and copper.
   4. *Feather ore of lead;* composed of sulphur, antimony and lead, with some iron and zinc.

5. *Nagyag tellurium ore;* composed of sulphur, antimony, lead, tellurium, gold, and copper.

V. Sulphur salts of copper.
   1. *Variegated copper ore;* composed of sulphur, iron, and copper.
   2. *Copper pyrites;* composed of sulphur, iron, and copper.
   3. *Bournonite;* composed of sulphur, antimony, lead, copper, and iron.
   4. *Grey copper ore;* composed of sulphur, antimony, arsenic, copper, silver, iron, and zinc.
   5. *Tennantite;* composed of sulphur, arsenic, copper, and iron.

VI. Sulphur salts of silver.
   1. *Cupreous sulphuret;* composed of sulphur, copper, and silver.
   2. *Brittle silver glance;* composed of sulphur, antimony, silver, with a little copper.
   3. *Dark red silver ore;* composed of sulphur, antimony, and silver.
   4. *Miargirite;* composed of sulphur, antimony, and silver, with some copper and iron.
   5. *Light red silver ore;* composed of sulphur, arsenic, and silver, with a little antimony.
   6. *Polybasite;* composed of sulphur, antimony, arsenic, silver, and copper, with a trace of iron.

From the preceding list it appears that the number of sulphur salts which have been met with in the mineral kingdom, amount to 21 species. The acid in all of these species except two is either sulphide of arsenic, or sulphide of antimony. The bases are sulphurets of iron, nickel, cobalt, lead, copper, or silver. The two exceptions are variegated copper ore and copper pyrites, in which the constituents are sulphur, iron, and copper. In them the sulphur is combined with two bases. But it is probable that the sulphuret of iron acts in them the part of an acid, and thus brings these two species under the class of sulphur salts. But the mode of analyzing these two species has been already given in the eighth section of this chapter, while treating of the mode of analyzing disulphuret of copper. We have only at present to treat of the mode of analyzing the other 19 species, all of which contain sulphide of antimony, or sulphide of arsenic, united to one or more sulphurets which act the part of a base.

Nickel glance may be digested in dilute nitric acid till every thing be dissolved, except a portion of sulphur, which is separated, washed, dried, and weighed. The liquid which passes through the filter contains a quantity of sulphur converted into sulphuric acid. This acid is thrown down by chloride of barium, and the sulphur calculated from the sulphate of barytes in the way already explained.

The liquid thus freed from sulphuric acid must next be freed from any barytes which it may contain by means of sulphuric acid, and a current of sulphuretted hydrogen gas is passed through it till all the arsenic is thrown down. The sulphuret of arsenic thus obtained may be dissolved in ammonia, in order to get rid of a quantity of loose sulphur with which it is always mixed. If we deduce the weight of the sulphur thus separated from that of the original weight of the precipitate, the remainder will be the true weight of the sulphuret of arsenic. Every 7·75 grains of this sulphuret are equivalent to 4·75 grains of metallic arsenic. But as the quantity of sulphur combined with arsenic is apt to vary, the best method of proceeding is to weigh out a portion of the sulphuret of arsenic obtained, and to digest it in aqua regia till the arsenic is acidified. Separate the sulphur remaining and weigh it. Throw down the sulphuric acid formed by means of chloride of barium, taking care that so much free acid exists in it as will prevent the arsenic acid from being thrown down, and determine the sulphur in the sulphate of barytes obtained in the way already explained. Subtract the weight of sulphur thus determined from that of the sulphuret examined, the remainder will be the weight of the arsenic which it contains.

From the liquid thus freed from arsenic drive off the sulphuretted hydrogen, and digest it with some nitric acid to peroxidize the iron. Neutralize and throw down the peroxide of iron by benzoate of ammonia. Finally throw down the oxide of nickel by carbonate of soda, wash, dry, and ignite. Every 4¼ grains of it are equivalent to 3·25 grains of metallic nickel.

A similar process will answer for analyzing the *sulpho-antimonite of nickel*, and for *cobalt glance*.

Zinkenite may be analyzed most accurately in the following way:—A quantity of the ore in powder is put into a glass bulb, connected with an apparatus by which dry chlorine gas can be passed over it, and the resulting compound conveyed by means of a glass tube into a covered vessel filled with water. Heat being applied to the bulb the sulphur and the antimony pass over into the receiver in the state of chlorides. The liquid in the receiver must consist of a weak solution of tartaric and muriatic acids. If we persist in passing chlorine into the receiver, the whole sulphur is at last acidified. Its quantity is determined by throwing down the sulphuric acid by means of chloride of barium, and estimating the sulphur from the quantity of sulphate of barytes obtained. The antimony is then thrown down by a current of sulphuretted hydrogen gas, and the sulphuret of antimony is analyzed, and the quantity of antimony determined in the way already explained.

What remains in the glass bulb is a mixture of chlorides of lead and copper. It may be dissolved in boiling water, and the oxide of lead precipitated by means of sulphate of soda. The sulphate of lead, after its ignition, contains $\frac{13}{19}$ths, or 0·684 of its weight of metallic lead. The black oxide of copper which alone remains may be thrown down by caustic potash or soda, and its weight determined: $\frac{4}{5}$ths of that weight represent the quantity of metallic copper.

The method of analyzing *plagionite*, *Jamesonite*, and *feather ore* of lead is precisely the same.

Nagyag tellurium ore, or the *blättererz* of the French, may be digested in dilute nitric acid. The lead and tellurium are dissolved, and may be easily separated, for the oxide of tellurium is thrown down by heating the solution, and the lead may be obtained in the state of sulphate by means of sulphate of soda. There remains undissolved the gold, antimony in the state of oxide, and the copper and sulphur. Aqua regia will dissolve every thing except some sulphur and a little sulphate of lead. By burning off the sulphur, the quantity of sulphate of lead may be determined. Dilution with water will throw down the oxide of antimony. After washing and ignition, every 10 grains of it are equivalent to 8 grains of metallic antimony.

The acidified sulphur is precipitated by chloride of barium, and estimated as already explained. The gold is precipitated by nitrate of mercury, and the oxide of copper, by caustic potash or soda.

The analysis of *Bournonite*, *grey copper ore*, and *Tennantite*, is conducted so nearly in the same way as that of zinkenite, that no additional observations seem necessary.

Cupreous sulphuret of iron may be digested in nitric acid till every thing is dissolved, except a few flocks of sulphur, which are to be separated and weighed.

The silver is to be thrown down from the solution by means of common salt, and the sulphuric acid by means of chloride of barium. Nothing now remains in solution but the peroxide of iron and the black oxide of copper. If we neutralize the solution and heat it, the peroxide of iron precipitates, and may be collected and weighed. Caustic potash or soda will throw down the oxide of copper.

Brittle silver glance is to be treated with chlorine in the same way as zinkenite, and the sulphur and antimony estimated in the way already explained. What remains in the glass bulb, is chloride of silver and chloride of copper. Water dissolves off the latter and leaves the former. The oxide of copper is thrown down by caustic of potash, and its weight determined.

We may either estimate the quantity of silver from the chloride in the way already explained, or we may reduce it to metallic silver, by passing a current of dry hydrogen gas over it in a glass tube or bulb, while we apply heat. The chlorine passes off in the state of muriatic acid, and metallic silver remains.

The method of analyzing *dark red silver ore*, *miargarite*, *light red silver ore*, and *polybasite*, is precisely the same, so that no additional remarks are necessary.

CHAP. X.

ANALYSIS OF MINERAL SALTS.

THE salts which occur in the mineral kingdom are very numerous, indeed, by far the greater number of minerals constituting real chemical compounds, may be considered as salts more or less complex in their nature. But the term salt here is limited to simple salts, or combinations of a single acid with a single base; we shall include also a few double salts, consisting either of one base united to different acids, or of one acid combined at once with two different bases.

The salts (omitting the salts of ammonia, potash, and soda) hitherto observed in the mineral kingdom, constitute twelve different sets, namely,

1. Hydrates,
2. Carbonates,
3. Sulphates,
4. Phosphates,
5. Arseniates,
6. Borates,
7. Vanadiates,
8. Chromates,
9. Molybdates,
10. Tungstates,
11. Columbates,
12. Titaniates.

The mode of analyzing each of these different sets will be explained in the following sections:—

Sect. 1. *Analysis of Hydrates.*

The only simple hydrates hitherto met with in the mineral kingdom, are the following:—

1. Hydrate of magnesia,
2. Hydrate of alumina, or Gibbsite,
3. Bihydrate of alumina,
4. Dihydrate of alumina, or diaspore,
5. Dihydrous peroxide of iron,
6. Hydrous peroxide of iron.

The mode of analyzing them is exceedingly simple. We first determine whether they contain water by heating a portion over a spirit lamp in a glass tube shut at one end. The water is driven off, and condenses on the cold part of the tube. We examine it by tasting it, and by applying test paper to know whether it contains any acid or alkali, or whether it be quite pure. After this preliminary experiment, we put a small quantity of the mineral, generally 100 grains, if we can dispose of so much, into a small green glass, or porcelain retort, to the extremity of which is luted a glass tube, filled with fragments of fused chloride of calcium. The weight of the retort is accurately determined, and also that of the glass tube filled with chloride of calcium. We now expose the retort to a heat gradually raised to redness, and keep it at that temperature till the whole water is driven out of the retort, or at least into the beak. The apparatus is then allowed to cool, and the tube, with chloride of calcium, being weighed again, the increase of weight indicates the water which it has absorbed. Should any water (as often happens) remain in the beak of the retort, we weigh the retort accurately and note down the weight. We now raise its temperature as high as that of boiling water, and pushing a glass tube open at both ends, as far into the retort as it will go, we suck out the air with our mouth, thus causing a current of air to pass through the hot beak: the water is speedily carried off, and the beak becomes dry. We then weigh again; the difference between the two weights gives the quantity of water drawn out. The loss of weight sustained by the mineral, compared with the water thus obtained, enables us to know whether any thing else besides water has been driven off. The only other volatile matter likely to be driven off, is carbonic acid, the presence of which would be shown by the effervescence which would take place when a portion of the mineral is digested in an acid.

What remains in the retort after the water has been driven off, is either magnesia, alumina, or peroxide of iron. It is to be examined, and its nature ascertained by the rules formerly laid down, when treating of the analysis of stony bodies.

Sect. 2. *Analysis of Carbonates.*

The carbonates at present known to exist in the mineral kingdom, amount to about 18: namely,

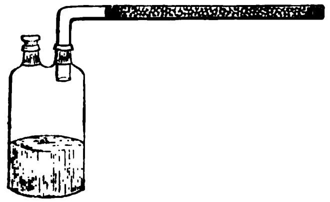
1. Carbonate of barytes,
2. Carbonate of strontian,
3. Carbonate of lime,
4. Subsesqui-carbon. of lime,
5. Baryto-carbonate of lime,
6. Carbonate of magnesia,
7. Hydro-carbonate of magnesia,
8. Carbonate of iron,
9. Junkerite,
10. Carbonate of manganese,
11. Carbonate of zinc,
12. Carbonate of lead,
13. Sulphato-carbonate of lead,
14. Cupreo-sulphato-carbonate of lead,
15. Carbonate of bismuth,
16. Carbonate of copper,
17. Hydro-carbonate of copper,
18. Carbonate of silver.

From all of these carbonates, except the five first, the carbonic acid is driven off by a red heat. We have only to put a given weight of them into a bottle glass retort, as described in the last section, and lute to its beak a tube filled with fragments of chloride of calcium. We then expose the retort to a red heat, sufficiently strong and long continued, to drive off the whole carbonic acid. We then allow the apparatus to cool, and weigh the retort with its contents, and also the glass tube with the chloride of calcium. The loss of weight indicates the carbonic acid given off, while the increase of weight of the tube with the chloride of calcium, gives the water of the mineral, if it contains any.

It is needless to observe, that before we proceed to determine the quantity of carbonic acid and water in a mineral, we must, by previous experiments, ascertain that carbonic acid is present, and also what the nature of the other constituent may be.

The nature of the base remaining in the retort, is determined by the rules already laid down.

Were we to attempt the analysis of carbonates of barytes, strontian, or lime, by the above method, we would fail. From barytes and strontian, we cannot drive off carbonic acid by heat, and a white heat is requisite before lime can be freed from that acid. We must therefore determine the quantity of carbonic acid in these bodies by dissolving them in an acid, and the best acid for the purpose is nitric acid moderately concentrated. The method which I employ is the following:—A small glass flask is procured with two mouths. To the one is fitted a glass stopper, pretty conical, and ground air-tight. To the other is luted a glass tube, bent at right angles, and filled with fragments of chloride of calcium. A quantity of nitric acid sufficient to dissolve the quantity of mineral to be experimented on is put into the flask, and the whole is then accurately counterpoised in a pair of scales, sufficiently delicate to turn when so loaded, with the tenth part of a grain. The mineral in small lumps (not in powder) is then weighed out, (I usually employ 100 grains,) and thrown as speedily as possible into the flask, which must be held obliquely to prevent any of the acid from being driven out of the flask by the effervescence which ensues. The stopper is then replaced as speedily as possible. As the carbonate dissolves, the carbonic acid gas makes its escape through the tube filled with fragments of chloride of calcium. I allow the whole to remain for twenty-four hours after the solution is completed, by which time all the carbonic acid has made its escape out of the flask, which will be found filled with common air, as at first. The whole is now weighed, as at first. The loss of weight gives the quantity of carbonic acid driven off. What remains in the flask, is the base of the carbonate dissolved in nitric acid. If we concentrate the solution sufficiently, we obtain crystals, if the base was barytes or strontian; but the solution does not crystallize when lime constitutes the base. The shape of the crystals is an octahedron, whether the base be barytes or strontian. If we put one of these crystals into the wick of a candle, the flame assumes a yellow colour if the base be barytes, but a beautiful red, if the base be strontian. If the



base be a mixture of lime and barytes, or strontian, we evaporate the nitric acid solution to dryness, and digest the dry residue in absolute alcohol. The nitrate of lime will dissolve, and will be obtained by evaporating the alcohol to dryness, but the nitrate of barytes or strontian will remain undissolved.

If the base be a mixture of barytes and strontian, we evaporate the nitric acid solution as before, to dryness, re-dissolve the dry residue in water, and throw down the barytes and strontian by carbonate of soda. The precipitate after being well washed, is dissolved in muriatic acid, and the solution evaporated to dryness. The residual salt being digested in absolute alcohol, the chloride of strontium dissolves, but the chloride of barium remains undissolved. Having thus separated the two bases, we convert them into carbonates or sulphates. These, after ignition, give us the quantities of barytes and strontian respectively. Every 12·25 grains of carbonate, and every 14·5 grains of sulphate of barytes, contain 9·5 grains of barytes. Every 9·25 of carbonate, and every 11·5 of sulphate of strontian, contain 6·5 grains of strontian.

When the base consists of a mixture of lime, magnesia, and oxide of iron, as sometimes happens, these three substances are to be separated from each other by the rules laid down when treating of the analysis of stony bodies.

Sect. 3. *Analysis of Sulphates.*

The sulphates in the mineral kingdom are still more numerous than the carbonates, amounting to no fewer than twenty-four species: namely,

1. Sulphate of barytes,
2. Calcareo-sulph. of barytes,
3. Sulphate of strontian,
4. Baryto-sulphate of strontian,
5. Calcareo-sulphate of strontian,
6. Hydrous sulphate of lime,
7. Anhydrous ditto.
8. Siliceous ditto.
9. Sulphate of magnesia,
10. Sulphate of alumina,
11. Ammonia-alum,
12. Soda-alum,
13. Potash-alum,
14. Alum stone,
15. Aluminite,
16. Sulphated perox. of iron,
17. Alumina-sulphate of iron,
18. Disulphate of cobalt,
19. Sulphate of zinc,
20. Sulphate of lead,
21. Sulphate of copper,
22. Tetrasulphate of copper,
23. Sulphated protoxide of uranium,
24. Sulphated peroxide of uranium.

Of these salts, there are twelve which are soluble in water;

namely, sulphate of magnesia, sulphate of alumina, ammonia alum, soda alum, potash alum, sulphated peroxide of iron, alumina-sulphate of iron, disulphate of cobalt, sulphate of zinc, sulphate of copper, and the two sulphates of uranium. To analyze these twelve, we dissolve them in water, and throw down the sulphuric acid by chloride of barium. The sulphate of barytes being washed, dried, and ignited, gives the quantity of sulphuric acid.

The bases require various precipitants, according to their nature. Magnesia is thrown down at a boiling temperature by carbonate of soda. Alumina is thrown down by carbonate of ammonia, and its purity is determined by its solubility in a ley of caustic potash or soda. The alumina from alum may be thrown down in the same way, but very long digestion is necessary before the sulphuric acid can be completely separated from it. Perhaps the following is an easier way of analyzing alum.

1. Determine the quantity of water by exposure to a moderate heat.

2. Take another equal portion of the alum, dissolve it in water, and throw down the sulphuric acid by chloride of barium; thus determining the quantity of acid which it contains.

3. Weigh out a third quantity of the same alum, expose it to a strong heat in a platinum crucible, and note the loss of weight. If the alum was ammonia alum, nothing will remain but the alumina. Now, as the weight of the water, acid, and alumina are known, we can easily determine the amount of the ammonia driven off, for the acid was saturated by the alumina and ammonia. Let the weight of alumina be a, we say $2{\cdot}25 : 5 :: a : \frac{5a}{2{\cdot}25} =$ weight of sulphuric acid combined with the alumina. Let the rest of the sulphuric acid weigh b, then we have $5 : 2{\cdot}125 :: b : \frac{2{\cdot}125b}{5} =$ weight of ammonia united to the sulphuric acid b.

If the alum be soda or potash alum, after exposure to a strong red heat, the alumina will be deprived of the acid with which it was combined, but the sulphate of soda or sulphate of potash will remain undecomposed, (unless the heat to which the salt has been exposed be too high). Digest the residue for a couple of days on the sand bath in distilled water, and separate the water from the alumina. The alumina being washed, dried, and ignited, its weight is ascertained. The aqueous solution being evaporated to dryness, will leave the sulphate of potash or of soda, the weight of which is to be determined, and it is easy to distinguish the potash from the soda by the solubility, the shape of the crystals, or the addition of some tartaric acid to the solution. If the salt be potash, bitartrate of potash immediately falls, but if it be soda, no precipitate appears.

From the *alumina-sulphate of iron*, the bases may be thrown down by carbonate of ammonia, taking care, in the first place, to peroxidize the iron. The alumina is separated from the iron, by boiling in caustic potash or soda ley.

The oxide of cobalt may be thrown down by caustic potash or soda; the oxide of zinc by carbonate of soda, at a boiling temperature; the oxide of copper by caustic potash or soda. To precipitate the protoxide of uranium, we must, in the first place, peroxidize it, and then it is thrown down by caustic ammonia. We must wash it not with water, but with a solution of sal ammoniac, otherwise it will pass through the filter. We then dry and ignite it, and weigh it. It is by this process converted into protoxide of uranium. When the oxide in the salt was peroxide, we easily obtain its weight by calculation, every 27 grains of protoxide being equivalent to 28 grains of peroxide.

The remaining 12 sulphates are insoluble in water, or nearly so; we must therefore proceed with their analysis in a different manner.

All the sulphates of lime are easily decomposed by reducing them to a fine powder, and boiling them for some hours with a solution of carbonate of soda. We then filter off the solution, saturate the alkali with muriatic acid, and throw down the sulphuric acid by means of chloride of barium.

The lime remains in the state of carbonate. It may be dissolved in muriatic acid, and tested for iron and magnesia. If it be found pure we may estimate the lime from the carbonate, every 6·25 grains of carbonate being equivalent to 3·5 grains of lime. If silica be present it will remain undissolved, when the carbonate of lime is taken up by muriatic acid.

The sulphates of barytes and strontian are not so easily decomposed as sulphate of lime. We must reduce them to a fine powder, mix them intimately with thrice their weight of anhydrous carbonate of soda, and fuse the mixture in a platinum crucible, and keep it in fusion for at least a couple of hours. We then dissolve out the alkali by digesting the fused mass in water. The alkali is saturated with muriatic acid, and the sulphuric acid, with which it has combined by double decomposition is thrown down by chloride of barium, and its quantity determined by the methods already more than once explained.

The undissolved matter, consisting of carbonate of barytes, or strontian, is digested in muriatic acid till a complete solution is obtained. Should any thing remain undissolved, it is a proof that the decomposition has not been complete. We must fuse it again with carbonate of soda, and proceed as before directed till we have obtained a complete separation of the acid and base, and a complete solution of the base in muriatic acid. We then test the muriatic solution to determine whether it consists of barytes or strontian, or whether it contains any lime. If it consists of pure barytes we throw it down by means of sulphate of soda. The precipitate after being washed, dried, and ignited, is pure sulphate of barytes, every 14·5 grains of which are equivalent to 9·5 grains of barytes.

When strontian constitutes the base we proceed in the same way, every 11·5 grains of its sulphate is equivalent to 6·5 grains of strontian.

Should the base be a mixture of barytes and strontian, we evaporate the muriatic solution to dryness, and digest the salt obtained in absolute alcohol. The chloride of strontium is dissolved, but the chloride of barium remains untouched. Having thus separated the two chlorides, we throw down their respective bases by sulphate of soda, and estimate the quantity of each as before explained.

If the base be a mixture of lime and barytes or strontian, we dissolve it in nitric acid instead of muriatic, evaporate the solution to dryness, and digest the residual salt in absolute alcohol. The nitrate of lime will be dissolved, but the nitrate of barytes, or of strontian, will remain. The salts being thus separated, the quantity of each of the bases is determined as before explained.

Aluminite, which is a tris-sulphate of alumina, may be dissolved by digestion in muriatic acid. From the solution the alumina may be thrown down by carbonate of ammonia, and the sulphuric acid by chloride of barium.

Alumstone is precisely similar in its composition to potash alum, excepting that each of the atoms of alumina is combined with only the third part of an atom of sulphuric acid instead of a whole atom. This renders it insoluble in water. We must therefore dissolve it by digestion in muriatic acid. The alumina may be precipitated by carbonate of ammonia, and the sulphuric acid by chloride of barium. By depriving another portion dissolved in muriatic acid of its alumina, evaporating to dryness and ignition, we obtain the sulphate of potash, from which the quantity of potash is easily estimated. Finally the water is known either by the loss or by exposing the mineral to a heat scarcely amounting to ignition.

Sulphate of lead may be decomposed by fusion with carbonate of soda. The oxide of lead remaining after washing off the alkali may be dissolved in nitric acid, and after the solution has been tested to ascertain its purity, the oxide of lead may be thrown down by sulphate of soda. Every 19 grains of ignited sulphate of lead being equivalent to 14 grains of oxide of lead. The quantity of sulphuric acid is determined in the way already explained.

The *tetrasulphate of copper* may be dissolved in muriatic acid, and the copper thrown down by caustic potash or soda, and the sulphuric acid by chloride of barium.

Sect. 4. *Analysis of Phosphates.*

The phosphates already known to exist in the mineral kingdom amount to 18 species; namely,

1. Subsesquiphosphate of lime.
2. Wavellite, or phosphate of alumina.
3. Lazulite, or diphosphate of alumina and magnesia.
4. Blue spar, or diphosphate of alumina and magnesia.
5. Phosphate of yttria.
6. Mullicite, or diphosphate of iron.
7. Subsesquiphosphate of iron.
8. Vivianite, or phosphate of iron.
9. Cacoxenite, or diphosphated peroxide of iron, combined with silicate of alumina and water.
10. Native Prussian blue.
11. Manganese-phosphate of iron.
12. Huraulite, or phosphate of manganese and iron.
13. Chloro-phosphate of lead.
14. Diphosphate of copper.

15. Pelokonite.
16. Sub-bisesquiphosphate of copper.
17. Uranite.
18. Chalcolite.

Not one of these salts is soluble in water, so that they all require certain processes to enable us to subject them to analysis. The analysis of the phosphates is attended with much greater difficulties than the analysis of any other class of bodies in the mineral kingdom. It will be requisite on that account to enter somewhat into detail, in order to smooth the difficulties as much as possible.

Phosphoric acid in the solid glacial state in which it is usually exhibited is a compound of real phosphoric acid and water, most commonly one atom acid and one atom water, though Rose obtained it with only the third part of an atom of water united to an atom of real acid. If we heat it in vessels of glass or porcelain it attacks them powerfully, and becomes in consequence less volatile, and only partially soluble in water.

All the phosphates are insoluble in water except the alkaline. But they dissolve easily in an excess of nitric, or muriatic acid, and even frequently in phosphoric acid. After ignition the greater number of them are insoluble in all acids, except the concentrated sulphuric, in which they dissolve at a boiling heat. But of course those phosphates whose bases form with sulphuric acid an insoluble compound, barytes, strontian, and oxide of lead, for example, cannot be dissolved by this process.

The neutral alkaline phosphates afford precipitates with all the earthy and metalline salts. These precipitates are phosphates consisting of phosphoric acid, combined with the precipitating base. They are soluble in acids, and again precipitated by alkalies. If we add a considerable excess of alkali they are often decomposed, at least partially, and the base appears with its characteristic properties. Precipitated phosphate of lime and some other phosphates, dissolve readily in a solution of sal ammoniac. But if we add caustic ammonia almost the whole of the phosphate is again precipitated. The precipitated phosphate of lead, formed by adding acetate or nitrate of lead to an alkaline phosphate, is insoluble in acetic, but soluble in nitric acid.

Nitrate of silver throws down a yellow precipitate from neutral solutions of a phosphate. This is the most characteristic of all the precipitates of phosphates, and is therefore usually employed to detect the presence of phosphoric acid in neutral solutions. If the phosphate has been recently ignited, the precipitate by nitrate of silver is not yellow but white. Arsenic acid indeed gives also a yellow precipitate with nitrate of silver, but the presence of arsenic acid in any compound is easily detected by means of the blowpipe.

Phosphate of barytes, of strontian, of lime, and of magnesia, are detected by their dissolving in muriatic acid, and being again precipitated by ammonia. But we must satisfy ourselves in the first place that the acid present in the compound is not arsenic, boracic, or fluoric. The two first are easily detected by the blowpipe, and the last by its corroding glass when the salt is drenched in sulphuric acid, and heated in a platinum crucible. The most difficult thing is to detect phosphoric acid when in combination with alumina. For phosphate of alumina and pure alumina have very nearly the same properties. In a subsequent part of this section the methods which have been devised for solving this difficult problem will be stated.

Thenard and Vauquelin have given us the following method of detecting phosphoric acid in a phosphate:—A small portion of potassium is put into the bottom of a small glass tube shut at one end, and the phosphate for examination is put upon the metal. This phosphate must be perfectly dry, but need not exceed a small fraction of a grain in weight. Heat the tube slowly to ignition. The potassium reduces the phosphoric acid and converts it into phosphuret of potassium. Pour a little mercury into the glass tube to remove any excess of potassium, and in about a minute pour it out again. Then blow cautiously through a fine tube upon the matter contained in the glass tube in order to moisten it. A strong and characteristic smell of phosphuretted hydrogen is immediately perceived.

According to Fuchs, if a solid phosphate be moistened with sulphuric acid, and held by a platinum forceps in the inner flame of the blowpipe it communicates a green colour to the outer flame.* This green colour continues only for a short time, and it does not always appear. It must be recollected too that borates produce a similar colour, indeed with them it is much finer and much deeper.

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* Schweigger's Jour. xxiv. 130.

Berzelius has given a method of detecting phosphoric acid by means of the blowpipe. A portion of the mineral for examination is fused with boracic acid on charcoal, and when the intumescence is ended a piece of fine harpischord wire is thrust into the bead in such a manner that the two ends of the wire project out of the bead. The whole is then strongly heated in the inner flame. The resulting bead when cold is taken from the charcoal, and wrapped up in a piece of paper, and then crushed in two by a slight blow of a hammer. We find a round grain of phosphuret of iron, which possesses a metallic appearance, is magnetic and brittle, so that it breaks in pieces when struck with a hammer. A small proportion of phosphoric acid cannot be detected by this method. The assay must contain no sulphuric acid, arsenic acid, nor any metallic oxide which is reduced by iron, otherwise globules would be obtained which could not be distinguished from phosphuret of iron.

We have no very modern analysis of phosphate of lime, but the analysis by Klaproth approaches pretty nearly to accuracy. He reduced the mineral to a fine powder, and dissolved it in muriatic acid. The muriatic acid solution was rendered as neutral as possible without precipitating the phosphate of lime, and then oxalate of ammonia was dropt into the liquid till all the lime was thrown down. The oxalate of lime was collected on a filter, washed, dried, and ignited. It was then in the state of carbonate of lime, every 6·25 grains of which are equivalent to 3·5 grains of lime. The liquid thus deprived of the lime was evaporated to dryness, and heated to drive off the ammoniacal salts. It was then weighed. Being dissolved in water, a quantity of undecomposed phosphate of lime remained, amounting to about $\frac{1}{14}$th of the original quantity subjected to analysis. This being deducted the remainder was considered as phosphoric acid.

In this analysis the obvious defect was the exposing the phosphoric acid to a red heat, because at that temperature a portion of it is volatilized. It would have been better to have saturated the acid with ammonia, which would have thrown down the undecomposed phosphate of lime. The liquid is now to be evaporated to dryness, and the dry salt intimately mixed with a quantity of oxide of lead more than sufficient to saturate the acid. Heat is then applied; the ammonia is displaced by the oxide of lead. After it has been disengaged we raise the heat to ignition, and then weigh the matter obtained. If from this weight we subtract that of the oxide of lead employed, the remainder is the weight of the phosphoric acid.

Wavellite is a salt composed of water, phosphoric acid, and alumina. Now, phosphate of alumina resembles alumina so closely in many of its characters that the phosphoric acid is apt to be overlooked altogether, and accordingly wavellite was long considered as a hydrate of alumina. Phosphate of alumina dissolves in nitric and muriatic acids; it dissolves also in caustic potash or soda ley, and it is precipitated from these solutions precisely as alumina is.

The method of separating alumina from phosphoric acid was first suggested by Professor Fuchs, and is as follows:—The weighed compound is dissolved in a solution of caustic potash, and to this liquid a solution of silicate of potash (or liquor of flints, as it was formerly called,) is added. This addition converts the whole into a thick slimy mass, which is diluted with water, and made to boil. An abundant precipitate falls, which is potash-silicate of alumina. This precipitate is separated, washed, and dissolved in muriatic acid. Being evaporated to dryness, the silica is separated in the usual way, and the alumina is thrown down from the muriatic acid solution, either by carbonate of ammonia or sal ammoniac.

The solution, filtered from the precipitated potash-silicate, contains the phosphoric acid combined with potash. It may be neutralized, and mixed with a neutral solution of chloride of calcium. Phosphate of lime precipitates, composed of 1 atom phosphoric acid and 1½ atom lime: so that every 9·75 grains of it are equivalent to 4·5 grains of phosphoric acid.

The method employed by Berzelius was merely a modification of the preceding. He mixed 2 parts of wavellite with 1½ parts of silica in fine powder, and 6 parts of carbonate of soda. The mixture was ignited for half an hour. It was then digested in water, till every thing soluble was taken up. The liquid portion contained the phosphoric acid united to soda, together with a little silicate of soda. On adding carbonate of ammonia, and digesting, the silica precipitated. The alkaline liquid was now reduced by concentration to half its bulk, in order to get rid of the excess of ammonia. It was then neutralized by muriatic acid, and left till the carbonic acid was dissipated. It was then supersaturated with caustic ammonia, which occasioned the precipitation of a little silica. The liquid was now mixed with chloride of calcium, added as long as any precipitate fell. This precipitate, after being well washed, was ignited and weighed. It was a mixture of subsesquiphosphate and fluate of lime. It was dissolved in muriatic acid, and sulphuric acid being added, the whole was evaporated to get rid of the flnoric acid. It was allowed to cool, and digested in alcohol. The whole was dissolved except the sulphate of lime, which was ignited and weighed. It contained, of course, the lime united in the mineral both with the phosphoric and fluoric acids. From the weight of sulphate it is easy to deduce that of the lime; for every 8·5 grains of anhydrous gypsum are equivalent to 3·5 grains of lime.

The alcoholic liquid contained the phosphoric acid mixed with sulphuric acid. The alcohol was evaporated off, water was added, and a sufficient quantity of muriatic acid, to prevent the precipitation of phosphate of barytes. Chloride of barium was then added to throw down the sulphuric acid. The liquid thus freed from sulphuric acid was filtered and mixed with a great excess of caustic ammonia, in order to precipitate the phosphate in the state of what has been called *intermediate subphosphate of barytes*. It is composed of 1 atom barytes, and 0·8 atom phosphoric acid: hence every 13·1 grains of it contain 3·6 grains of phosphoric acid. Subtracting the quantity of phosphoric acid from that of the original weight of the two acids, the remainder gives the weight of fluoric acid.

The soda-silicate of alumina was dissolved in muriatic acid, and evaporated to dryness to get rid of the silica. The alumina was then separated in the usual manner, and a small quantity of oxides of iron and manganese were obtained by digesting the precipitate in caustic potash.

The water was determined in the usual manner by exposing a given weight of wavellite to ignition in a small retort, to the beak of which a tube filled with fragments of chloride of calcium was luted.*

Lazulite and *blue spar*, which contain magnesia, silica, oxide of iron, and lime, besides phosphoric acid and alumina, require for their analysis a preliminary process. A portion of the mineral, reduced to a fine powder, is digested in a platinum crucible, with a sufficient quantity of caustic potash ley. The heat is continued 'till the watery portion evaporates, and the

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* Ann. de Chim. et de Phys. xii. 16.

dry mass is at last raised to ignition. The matter thus treated is digested in water till every thing soluble is taken up, and the insoluble portion collected on a filter. The silica, lime, magnesia, oxide of iron, and a small portion of alumina remain undissolved, while the alkaline solution contains the phosphoric acid and the alumina. It is mixed with silicated potash ley in sufficient quantity, and boiled. The potash-silicate of alumina precipitates, and is to be treated as already explained. The phosphoric acid is to be thrown down by chloride of calcium, and its quantity estimated in the way already explained.

If we boil the precipitate collected on the filter with a solution of sal ammoniac, the magnesia will be dissolved, while the silica, the alumina, oxide of iron, and lime, if any be present, will remain. These substances are to be separated from each other in the way already explained, when treating of the analysis of stony bodies.

Phosphate of yttria was analyzed by Berzelius in the following manner:—

A portion of the mineral in fine powder was mixed with three times its weight of carbonate of soda, and the mixture heated till the mass fused, and all evolution of carbonic acid was at an end. The fused mass was digested in water till every thing soluble was taken up. The undissolved portion was collected on a filter.

The liquid which contained the phosphoric acid being saturated with acetic acid, evaporated to dryness, and the residual salt dissolved in water, a trace of silica remained behind too small to be weighed. The phosphoric acid was precipitated by acetate of lead. The precipitate is a subsesquiphosphate of lead, every 25·5 grains of which are equivalent to 4·5 grains of phosphoric acid. For greater security the phosphate of lead should be converted into sulphate of lead, composed of 14 grains oxide of lead and 5 grains of sulphuric acid. This gives the weight of the oxide of lead, from which that of the phosphoric acid in the phosphate is easily deduced. The phosphoric acid being examined in the usual way, was found to contain a small quantity of fluoric acid mixed with it.

The portion undissolved by the water being digested in muriatic acid, left a small residue consisting partly of silica and partly of undecomposed mineral. The muriatic solution was dropt into a solution of carbonate of ammonia, by which the matter at first precipitated was again re-dissolved. The liquid was evaporated to dryness, the sal ammoniac driven off, and the residual matter dissolved in muriatic acid, and the solution evaporated to dryness. Being again digested in water a dark brown substance remained undissolved. It was ignited and then digested in muriatic acid; about $\frac{2}{5}$ths of it dissolved. The dissolved portion was subphosphate of iron, with a trace of subsesquiphosphate of lime. The undissolved portion possessed the characters of zirconia, but it was not particularly examined. The subphosphate of iron and the zirconia being subtracted from the weight of the undissolved matter originally remaining when the mineral heated with carbonate of soda was digested in water, left the quantity of yttria contained in the portion subjected to analysis. This matter was examined and found to possess the characters of yttria.*

The different species of *phosphated iron*, namely, Mullicite, subsesquiphosphate, Vivianite, cacoxenite, and native Prussian blue, may be analyzed in the following manner:—

By exposure to heat the water is driven off, and its weight estimated.

The anhydrous residue being digested in muriatic acid, every thing dissolves except some grains of siliceous matter, which may be accidentally present.

Let the muriatic solution be mixed with sulphohydrate of ammonia: the iron is thrown down in the state of sulphuret, and may be separated by the filter after the liquid has been deprived of its excess of sulphohydrate of ammonia by boiling it with a mixture of some muriatic acid.

The sulphuret of iron is to be dissolved in aqua regia, and the peroxide of iron thrown down by an alkaline carbonate. After edulcoration and ignition every 5 grains of it are equivalent to 4·5 grains of protoxide of iron.

The liquid freed from iron contains the phosphoric acid, which may be thrown down (after neutralizing the liquid) by chloride of barium. Let the phosphate of barytes be washed, dried, ignited, and weighed. Let it then be dissolved in muriatic acid. Should any sulphate of barytes be present (which might happen through some impurity in the reagents) it will remain undissolved, and its weight must be deducted from that of the phosphate of barytes originally obtained.

Add sulphuric acid to the muriatic acid solution. The barytes will be thrown down in the state of sulphate. Let

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* Köng. Vet. Acad. Handl., 1824, p. 336.

this sulphate be collected, dried, ignited and weighed. From the weight we easily deduce that of the barytes which it contains; and subtracting this weight from that of the phosphate of barytes originally obtained, the remainder gives the weight of the phosphoric acid in the mineral.

The phosphate of barytes thrown down is usually a subsesquiphosphate, composed of 1 atom of phosphoric acid and 1½ atom barytes. But the phosphoric acid forms so many compounds with each base, that it would not be safe to calculate from such a salt without actual analysis; and the conversion of the phosphate into the sulphate of barytes affords the easiest analysis that we can apply.

The analysis of *manganeso-phosphate of iron* and of *Huraulite* can occasion no difficulty after the remarks already made. The oxides of iron and manganese are easily separated, by peroxidizing the iron, and throwing it down by benzoate of ammonia; or we may prevent the oxide of manganese from falling by adding sal ammoniac to the solution, and then throwing down the iron by ammonia; or we may peroxidize the manganese by chlorine, and then throw it down by bicarbonate of potash.

Chloro-phosphate of lead consists essentially of chloride of lead and subsesquiphosphate of lead, but it contains occasionally oxide of iron, and from Kersten's analysis we learn that in the brown varieties lime constitutes an occasional constituent, and that it likewise contains fluoric acid. To analyze it the simplest method is to dissolve it in nitric acid, and to throw down the chlorine from the solution by means of nitrate of silver. The chloride of silver is washed, dried, fused, and weighed. Every 18·25 grains of it are equivalent to 4·5 grains of chlorine.

The liquid thus freed from chlorine must be freed from any excess of silver accidentally added, by a few drops of muriatic acid. A current of sulphuretted hydrogen being then passed through it, the lead is precipitated in the state of sulphuret, every 15 grains of which are equivalent to 14 grains of oxide of lead. The addition of sulphuric acid and alcohol will throw down the lime in the state of sulphate, every 8½ grains of which after ignition are equal to 3½ grains of lime.

Having thus separated the lime and the lead, we add chloride of barium to the remaining liquid, taking care that it contains a sufficient excess of acid to prevent the precipitation of the phosphate of barytes. After the sulphate of barytes has precipitated and been separated, we neutralize the solution by ammonia, taking care not to add any excess, to avoid throwing down the oxide of iron, if any should be present. The phosphate of barytes precipitates; and from it the quantity of phosphoric acid may be determined, in the way already explained. Finally, the peroxide of iron is thrown down by ammonia, washed, dried, and ignited. We must take care of two things in the last part of this analysis: 1st, that the oxide of iron do not fall with the phosphate of barytes; and 2d, that the iron be not in the state of phosphate when thrown down, which might very easily be the case if the requisite precautions be not taken.*

Diphosphate of copper dissolves readily in nitric acid. From the solution sulphuretted hydrogen throws down the copper. From this sulphuret the quantity of oxide of copper is determined, in the way already explained. The phosphoric acid may now be thrown down by means of chloride of barium or nitrate of lead, and the quantity of phosphoric acid determined from the precipitate, in the way already explained.

The analysis of pelokonite and subbisesquiphosphate of copper may be conducted upon the same principles; only to separate the oxides of iron and manganese we must employ sulphohydrate of ammonia, after having thrown down the copper by a current of sulphuretted hydrogen.

Uranite contains a great number of constituents, though it consists chiefly of phosphated peroxide of uranium and subsesquiphosphate of lime. The other constituents, not reckoning the water, are barytes, magnesia, manganese, and a trace of fluoric acid. It may be analyzed in the following manner:—

After determining the water, by igniting the mineral, it is dissolved in nitric acid, and the solution mixed with alcohol. To this mixture sulphuric acid, previously diluted with alcohol, is added, as long as sulphate of lime continues to precipitate. The gypsum thus obtained is washed with alcohol, dried, ignited, and weighed. It is to be dissolved in muriatic acid by the assistance of heat; a little sulphate of barytes remains undissolved. This is to be washed, dried, ignited, and weighed. Being subtracted from the weight of the original precipitate, the remainder gives the amount of the gypsum. The weight of the gypsum and sulphate of barytes being

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* The only sure way of proceeding is to throw down the iron by means of sulphohydrate of ammonia.

known, it is easy to deduce from them the quantity of lime and barytes contained in the mineral.

The alcoholic solution is now to be evaporated to dryness, and the residue being intimately mixed with carbonate of soda, is exposed to a strong red heat, in order to obtain by double decomposition the phosphoric acid united to the soda, and the peroxide of uranium also united to soda. Water dissolves the former of these compounds, but leaves the latter undissolved.

The uraniate of soda thus remaining is to be dissolved in muriatic acid, from which the peroxide of uranium is thrown down by caustic ammonia. The precipitate being washed with a solution of sal ammoniac, is dried, ignited, and weighed. It is now pure protoxide of uranium, every 27 grains of which represent 28 grains of peroxide.

When the ammoniacal solution is neutralized by muriatic acid a scanty white precipitate usually appears. This, according to Berzelius, is a mixture of phosphated peroxide of uranium, and phosphated peroxide of tin.

The liquid now contains nothing but the phosphoric acid united to an alkali. Let it be acidulated and boiled till the carbonic acid is completely driven off, and then let a mixture of chloride of calcium and ammonia be added. The subsesquiphosphate of lime is precipitated, from which the quantity of phosphoric acid is determined, in the way already explained.

The analysis of *chalcolite* may be conducted in nearly the same way, excepting that from the solution containing the oxides of copper and uranium we must throw down the copper by sulphuretted hydrogen; and as no lime or barytes is present, we have no occasion to throw these bodies down by means of sulphuric acid and alcohol. We at once fuse a mixture of chalcolite and carbonate of soda; the solution contains the phosphoric acid, which is to be obtained as already explained. The undissolved matter contains the oxides of copper and uranium; it is to be dissolved in muriatic acid. The copper is to be thrown down by sulphuretted hydrogen, and the oxide of uranium by caustic ammonia.

Sect. 5. *Analysis of Arseniates.*

The arseniates known at present to exist in the mineral kingdom amount to 15 species; namely,

1. Sesquihydrous arseniate of lime,
2. Bisesquihydrous arseniate of lime,
3. Diarseniate of iron,

4. Subsesquiarseniate of iron,
5. Arseniate of iron,
6. Diarseniate of nickel,
7. Diarseniate of cobalt,
8. Arseniate of lead,
9. Hydrous subbisesquiarseniate of copper,
10. Diarseniate of copper,
11. Prismatic oliven ore,
12. Acicular oliven ore,
13. Copper mica,
14. Octahedral arseniate of copper,
15. Copper schaum.

All these arseniates are insoluble in water; but the presence of arsenic acid, or at least of arsenic, in a mineral is easily discovered by heating a fragment of it on charcoal before the blowpipe. White fumes of arsenious acid are driven off, which possess the well known alliaceous smell which characterizes arsenic. If a mineral destitute of the metallic lustre gives out arsenical fumes before the blowpipe, we may conclude that it contains arsenic acid.

The arseniates are all insoluble in water, except those which have an alkali for their base. But the insoluble arseniates dissolve readily in muriatic acid, except when the base happens to form an insoluble salt with muriatic acid, in which case they dissolve in nitric acid. If through the acid solution of an arseniate, rendered as neutral as possible without causing the salt to fall, we pass a current of sulphuretted hydrogen gas, the well known yellow sulphuret of arsenic falls, which sufficiently characterizes the presence of arsenious or arsenic acid. It is true that cadmium strikes also a yellow colour when treated with sulphuretted hydrogen, but the nature of the mineral under examination is always sufficient to prevent our confounding together cadmium and arsenic.

The *arseniates of lime* present no peculiar difficulty in their analysis.

By exposing the mineral to incipient ignition we drive off the water, and determine its quantity. The anhydrous portion is then dissolved in nitric acid, and the solution, if the mineral be pure, takes place without any effervescence.

The arsenic acid may be thrown down by a current of sulphuretted hydrogen, and the quantity of arsenic acid deduced from that of the sulphuret in the way formerly explained; or we may precipitate the arsenic acid by means of nitrate of lead. The precipitate, after edulcoration and exposure to a red heat, is anhydrous arseniate of lead, every 21·25 grains of which are equivalent to 7·25 grains of arsenic acid; or after having thrown down the lime, magnesia and oxide of cobalt, which are usually present, we may add the requisite quantity of a salt of iron, and determine the weight of arsenic acid by Berthier's process, formerly explained.

After throwing down the whole arsenic acid by means of sulphuretted hydrogen, nothing remains in solution but the base of the salt. This base is lime, generally mixed with a little oxide of cobalt, and in the picropharmacolite of Stromeyer with some magnesia.

To the solution freed from sulphuretted hydrogen add a sufficient quantity of sulphuric acid to saturate the bases, and evaporate to dryness to get rid of the nitric acid. After exposure to a red heat, let the saline mass be weighed. Let it be digested in a little water till the sulphate of magnesia and the sulphate of cobalt are dissolved. The white matter remaining is sulphate of lime; let it be ignited and weighed. By repeated crystallizations and solutions the portion of sulphate of lime which had been at first dissolved may be obtained; or we may add to the solution of sulphate of magnesia and sulphate of cobalt, previously diluted with water, a sufficient quantity of oxalate of ammonia to throw down the residual lime.

The cobalt may be thrown down by sulphohydrate of ammonia. The sulphuret of cobalt obtained is to be dissolved in nitric acid, and the oxide of cobalt thrown down by caustic potash, washed, dried, ignited, and weighed. From the weight of oxide of cobalt it is easy to deduce that of sulphate of cobalt contained in the mixed sulphates; for every 4·25 grains of oxide of cobalt are equivalent to 9·25 grains of anhydrous sulphate. Knowing the weights of the sulphate of lime and of the sulphate of cobalt, we have only to add them together and deduct their sum from that of the sulphates originally obtained. The remainder is obviously the weight of the sulphate of magnesia; and anhydrous sulphate of magnesia contains the third part of its weight of magnesia.

The different *arseniates of iron* may be dissolved in muriatic acid, and the solution mixed with an excess of sulphohydrate of ammonia. The sulphuret of iron and of copper, if any be present, will be precipitated, while the arsenic will remain in solution.

Let the precipitate be digested in muriatic acid; the iron will be dissolved, but copper will remain. Let the residual black matter be roasted in an open vessel; it is now oxide of copper. Let the solution be digested with nitric acid, and the peroxide of iron thrown down by ammonia. After washing, drying, and ignition, it is peroxide of iron, every 5 grains of which are equivalent to 4·5 grains of protoxide of iron.

To the liquid in which the arsenic is held in solution by means of the sulphohydrate of ammonia, muriatic acid is to be added. Sulphuretted hydrogen is disengaged, and the sulphuret of arsenic is precipitated. Let it be washed and digested in aqua regia till the arsenic is acidified and dissolved. Let the undissolved sulphur be dried and weighed, and the sulphuric acid formed during the digestion in aqua regia be thrown down by chloride of barium, and the sulphur contained in it determined. Thus the weight of the sulphur becomes known. Subtracting this weight from that of the sulphuretted arsenic, the remainder gives the quantity of arsenic. From this quantity the amount of arsenic acid is easily deduced, for 4·75 grains arsenic are equivalent to 7·25 grains of arsenic acid.

If to the liquid thus freed from the bases and from arsenic acid we add a quantity of ammonia and of chloride of calcium, the phosphoric acid (if any be present) will be thrown down in the state of subsesquiphosphate of lime, every 9·75 grains of which are equivalent to 4·5 grains of phosphoric acid.

The *diarseniate of nickel*, when mixed with potash and ignited in a silver crucible, undergoes decomposition. The acid unites to the potash, while the oxide of nickel remains. Water removes the potash and arsenic acid. Let the oxide of nickel be ignited and weighed. To see whether it contain any oxide of cobalt let it be dissolved in muriatic acid, thrown down by carbonate of soda, and converted into oxalate by digestion in oxalic acid. Let the oxalate be dissolved in ammonia, and exposed for some days in a glass jar simply covered with paper. As the ammonia makes its escape the oxalate of nickel precipitates, but the oxalate of cobalt remains in solution. Let the liquid be decanted off, and the oxide of cobalt thrown down by caustic potash. Its weight after ignition being subtracted from that of the original base, will leave the weight of the oxide of nickel.

The arsenic acid united with the potash may be determined by the processes already sufficiently explained.

The *diarseniate of cobalt* may be analyzed precisely in the same way.

The *arseniate of lead* contains chlorine and phosphoric acid, and likewise a trace of fluoric acid. It may be dissolved in nitric acid, and the chlorine thrown down by nitrate of silver.

To the solution thus freed from chlorine, and from which all excess of silver has been removed by means of muriatic acid, sulphohydrate of ammonia may be added after the nitric acid has been neutralized by ammonia. The lead is thrown down in the state of sulphuret. Wash this sulphuret and digest it in nitric acid till it is converted into sulphate. Let this sulphate be ignited and weighed; every 19 grains of it are equivalent to 14 grains of oxide of lead.

Add muriatic acid to the solution containing sulphohydrate of ammonia; the arsenic will be thrown down in the state of a sulphuret. This sulphuret is to be washed and treated as already explained, in order to deduce from it the quantity of arsenic acid in the mineral. The residual liquid still contains the phosphoric acid. If we mix it with ammonia and chloride of calcium we obtain a precipitate of subsesquiphosphate of lime, from which the quantity of phosphoric acid is deduced, in the way already explained.

The seven species of *arseniated copper ores*, though differing in the proportions of their constituents, yet as the nature of the constituents is the same in all, namely water, oxide of copper, arsenic acid and phosphoric acid occasionally, may be all analyzed by a similar process.

Let the mineral be dissolved in nitric acid, after having heated it to drive off the water. Add an excess of ammonia, and then a sufficient quantity of sulphohydrate of ammonia to keep the arsenic in solution. The copper precipitates in the state of sulphuret. Let it be dissolved by digestion in nitric acid, and let the oxide of copper be precipitated by caustic potash, washed, dried, ignited, and weighed.

Add muriatic acid to the sulphohydrated solution; the sulphuret of arsenic precipitates. It is to be washed and treated as already explained, in order to deduce from it the weight of the arsenic acid in the mineral.

Nothing now remains but the phosphoric acid, which is thrown down in the state of subsesquiphosphate of lime by ammonia and chloride of calcium.

If we determine the water, and ascertain that the mineral contains only arsenic acid and oxide of copper, we have only to dissolve a given weight of the specimen in nitric acid, and throw down the oxide of copper by means of caustic potash or soda. This precipitate, being washed, dried, and ignited, gives the weight of oxide of copper, which being deduced from that of the anhydrous mineral analyzed, leaves the weight of arsenic acid with which it was combined.

Sect. 6. *Analysis of Borates.*

The minerals containing boracic acid hitherto met with in the mineral kingdom, are six; namely,

1. Borax, or biborate of soda,
2. Datholite, or borosilicate of lime,
3. Botryolite,
4. Biborate of magnesia,
5. Hydroboracite,
6. Tourmalin,

The presence of boracic acid in a mineral, is detected by pulverizing a small quantity of it, and after adding a few drops of sulphuric acid to the powder, pouring over it some alcohol, and setting the spirit on fire. If boracic acid be present the alcohol will burn with a green flame.*

Dr. Turner has given us the following method of detecting boracic acid in a mineral by the blowpipe: Mix the assay with a flux, composed of 1 part of fluor spar, and 4½ parts of bisulphate of potash. This mixture moistened with a little water, is attached to the extremity of a platinum wire, and exposed to the inner flame of a candle before the blowpipe. Shortly after fusion there appears a green colour around the flame, which soon disappears however, and is not again seen.

Boracic acid, when pure, forms a transparent brittle glass, which fuses at a red heat, and is not volatile. After fusion in a platinum crucible, it dissolves with difficulty in water. If it be dissolved in hot water, the solution deposits scales of hydrated boracic acid, which have a pearly lustre, and feel greasy. It dissolves very sparingly in water, and when we evaporate it, even in a low heat, a considerable portion of the acid is volatilized along with the water. This acid gives a reddish-brown colour to turmeric paper, as the alkalies do, but it reddens litmus paper. It is soluble in alcohol, and the alcoholic solution burns with a fine green-coloured flame.

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* The chlorides communicate also a green colour to the flame of alcohol when moistened with sulphuric acid, but in this case the flame is bluish-green, with boracic acid it is emerald-green.

This is the most characteristic property of boracic acid. A good deal of the boracic acid is volatilized along with the alcohol, if we attempt to evaporate it.

The borates, with the exception of those that have an alkali for their base, are very slightly soluble in water. Hence, chlorides of barium, strontium, and calcium, throw down white precipitates when mixed with a solution of a borate, provided it be not too dilute. But these precipitates dissolve in a large quantity of water, and still more readily in a solution of sal ammoniac.

Nitrate of lead throws down a white precipitate, nitrate of mercury a brown, and nitrate of silver throws down a white precipitate from concentrated solutions, but a brown precipitate from dilute solutions. These precipitates are very imperfectly soluble in water, but they dissolve readily in ammonia and in nitric acid.

When a soluble borate is boiled with sulphuric acid, it undergoes decomposition, and pearly scales of hydrated boracic acid are deposited.

The only accurate method of separating boracic acid from those minerals, of which it forms an essential constituent, is the following, which was first suggested by Arfvedson in 1822:* A weighed quantity of the borate, previously freed from water (if any be present) and in the state of a fine powder, is mixed with four times its weight of finely pulverized fluor spar, and this mixture being put into a platinum crucible, is made up into a thick pap with sulphuric acid. The whole is then heated and finally ignited, till all the excess of sulphuric acid is driven off. The fluoric acid as it is disengaged, combines with the boracic, and flies off in the state of fluoboric acid. Nothing at last remains but sulphate of lime from the fluor spar, and the base of the borate converted into a sulphate.

Suppose we were to analyze borax by this method; after the process is finished, nothing remains but sulphate of soda and sulphate of lime. If we digest the residue in water, the sulphate of soda will be dissolved, together with a little sulphate of lime. The addition of carbonate of ammonia, with some oxalate of ammonia, will throw down the lime. We then filter, evaporate to dryness, and ignite the residual salt to get rid of the sulphate of ammonia. Nothing remains but

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* Köng. Vet. Acad. Handl., 1822, p. 93.

anhydrous sulphate of soda, every 9 grains of which are equivalent to 4 grains of soda. Subtracting this soda from the original weight of the anhydrous borax submitted to analysis, the remainder gives the quantity of boracic acid which the salt contained.

Datholite, which contains silica, lime, boracic acid, and water, with a trace of iron and manganese, was analyzed by Klaproth in the following way:—

The proportion of water was determined by igniting a portion of the mineral.

A quantity of datholite reduced to a fine powder, was digested in dilute nitric acid, till the whole assumed the form of a jelly. After dilution with water and digestion, till the whole mineral was decomposed, the liquid was evaporated to dryness in a gentle heat. The dry mass being digested in water acidulated with nitric acid, left the silica, which was washed, dried, ignited, and weighed.

The nitric acid solution was mixed with sulphuric acid, and evaporated to dryness in a gentle heat. The residual matter was digested in alcohol; the spirits were drawn off into a retort and distilled; the boracic acid remained behind, and its quantity was estimated after ignition. What the alcohol left undissolved was sulphate of lime, which was also ignited and weighed. From its weight, that of the lime in the mineral was estimated.

In another experiment, he raised the nitric acid solution to the boiling temperature, and then added carbonate of soda in quantity sufficient to throw down the lime. From the quantity of carbonate of lime obtained, the lime was easily deduced. The solution still contained the boracic acid. It was saturated with sulphuric acid, evaporated to dryness, and the boracic acid extracted by alcohol, as before.*

From the properties of boracic acid, stated at the beginning of this section, it is obvious, that during Klaproth's analysis, a considerable portion of the boracic acid must have been volatilized and escaped detection. The mineral might be analyzed by two processes:—1. The quantity of silica and lime in the mineral must be accurately determined, by dissolving the datholite in nitric acid, evaporating the solution to dryness, separating the silica in the usual manner, and then throwing down the lime by oxalate of ammonia, and determining the quantity. The silica and lime deducted from the original

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* Gehlen's Jour. vi. 109.

weight of the anhydrous mineral, leave the quantity of boracic acid which the mineral contained. 2. For the abstraction of the silica and boracic acid, we add a quantity of pure fluor spar, equal to 2·375 times the weight of the silica, and 1·583 times the weight of the boracic acid, to a given portion of the anhydrous mineral. This mixture we drench with sulphuric acid, and heat. Every thing is driven off except sulphate of lime. The sulphate of lime from the fluor spar, amounts to 1·789 times the original weight of the fluor spar. This quantity subtracted from the total sulphate of lime left, gives the sulphate of lime from the lime of the datholite analyzed. And from this sulphate the weight of the lime is easily deduced. If we add this lime to that of the silica, and subtract the amount from that of the anhydrous datholite analyzed, the remainder must be the amount of the boracic acid.

The analysis of *boracite* and *hydroboracite*, must be conducted on the same principles. What remains after the expulsion of the boracic acid, is a mixture of sulphates of lime and magnesia. The method of analyzing such a mixture, and determining the quantity of magnesia, has been already explained.

To give the reader an idea of the way employed by analysts, to estimate the quantity of boracic acid in the tourmalin, the easiest method will be to state Leplay's analysis of one of these minerals.

Five parts of tourmalin in fine powder, were mixed with 15 parts of carbonate of lead, and 10 parts of nitrate of lead, and fused for a quarter of an hour in a covered platinum crucible. The glass was, when cold, dissolved in nitric acid, and the solution evaporated to dryness by a very gentle heat, to prevent the escape of boracic acid. The dry mass being digested in water acidulated with nitric acid, the silica was left. It was washed, and its quantity estimated in the usual manner.

A current of sulphuretted hydrogen gas was passed through the liquid to throw down the lead. The liquid was filtered and concentrated, till it was reduced almost to the state of a paste. It was then diluted with water, and a sufficient quantity of carbonate of ammonia added to throw down the alumina and peroxide of iron, without acting upon the lime and magnesia which the liquid contained. The alumina and oxide of iron thus obtained, were separated in the usual manner, and the quantity of each determined.

Oxalate of ammonia dropt into the liquid thus freed from alumina and oxide of iron, threw down the lime in the state of oxalate.

The liquid, which now contained potash, boracic acid, magnesia, nitric acid, and ammonia, was evaporated to dryness at a low heat, in a porcelain basin. The dry residue was put into a flat platinum vessel, and kept at a heat of incipient ignition, till the nitrate of magnesia was deprived of its acid. Care must be taken not to raise the heat too high, otherwise the boracic acid would be volatilized. The matter being now digested in boiling water, left the magnesia.

A few drops of nitric acid were added to the aqueous liquor, and it was gently evaporated to dryness, and the residual salt carefully weighed. Alcohol was then poured over it and set on fire. It burned with a green flame. New portions of alcohol were poured on and burned off in the same way, till the flame ceased to have a green tinge. This happened after 15 doses of alcohol had been employed. The residual salt was now weighed. This weight subtracted from the original weight of the salt, gave the weight of the boracic acid that had been volatilized with the burning alcohol.

The alkali only remained. The salt was dissolved in water, and sulphuric acid added to drive off the nitric acid. The whole was evaporated to dryness, and by the addition of a little carbonate of ammonia, all excess of sulphuric acid was got rid of. The salt was now dissolved in water, and the sulphuric acid thrown down by chloride of barium, and its quantity determined. It was found that the salt was a compound of

Sulphuric acid, .	105, or 5
Alkali, . .	113, or 5·38

From which he concluded that the alkali was potash.* It is obvious, however, that some soda must have been present. A mixture of 2 atoms potash and 1 atom soda, would make the alkali united to 5 sulphuric acid amount to 5·33, which is very nearly the quantity found by Leplay. Hence the alkali found by him, instead of being 2·32 per cent. potash, ought to have been

Potash, . . .	1·79
Soda, . . .	0·53
	2·32

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* Ann. de Chim. et de Phys. xlii. 272.

Sect. 7. *Analysis of Vanadiates.*

The only vanadiate known at present to exist in the mineral kingdom, is the *vanadiate of lead.* Besides vanadic acid and oxide of lead, it contains also chlorine, together with a trace of silica and oxide of iron.

By dissolving it in nitric acid and adding nitrate of silver, we throw down the chlorine, and determine its amount. A little muriatic acid will remove any excess of silver that may have been added.

We now mix the vanadiate deprived of its chlorine, and in the state of fine powder, with bisulphate of potash, and fuse the mixture in a platinum crucible. If we digest the fused mass in water the vanadic acid and excess of bisulphate of potash will be dissolved, and sulphate of lead will remain behind, every 19 grains of which are equivalent to 14 grains of oxide of lead.

The vanadic acid solution is now mixed with muriatic acid, and a little sugar, and boiled till it assumes a blue colour, a proof that it is converted into oxide of vanadium. Ammonia will throw down oxide. But the digestion with muriatic acid and sugar must be long continued before the whole vanadic acid is deoxidized. Every 10·5 grains of oxide of vanadium are equivalent to 11·5 grains of vanadic acid.

Sect. 8. *Analysis of Chromates.*

The only chromates hitherto met with in the mineral kingdom are the *chromate of lead* and *melanochroite,* which is a subsesquichromate of lead.

The colouring powers of chromic acid are so great that it is easily recognised when it enters as a constituent of a solid body. If we mix a little of the substance suspected [illegible] contain it with borax, and fuse it before the blowpipe on charcoal, the bead assumes a beautiful emerald green colour. This colour of course will be modified when metallic oxides capable of communicating colours to borax are present. If we heat a chromate with muriatic acid, chlorine is disengaged, and the acid assumes a dark green colour.

When a chromate is in solution in water, nitrate of lead throws down a fine yellow precipitate, and nitrated suboxide of mercury a deep red precipitate.

The analysis of chromate of lead is very simple. Reduce it to a fine powder, and digest it for some time in muriatic acid. If we pour alcohol into the mixture we dissolve off the chromic acid, and leave chloride of lead. Every 17½ grains of which after fusion are equivalent to 14 grains of oxide of lead. If we digest the alcoholic solution, and then add caustic ammonia, the chromic acid is separated in the state of green oxide, every 5 grains of which after ignition are equivalent to 6½ grains of chromic acid.

Sect. 9. *Analysis of Molybdates.*

The only molybdates hitherto met with in the mineral kingdom are *molybdate of lead* and *trismolybdate of lead.*

When molybdic acid or oxide is fused before the blowpipe on a platinum wire with biphosphate of soda, the bead in the inner flame assumes a beautiful green colour, which is permanent; in the outer flame the colour is weaker, and almost disappears when the bead is cold. When borax is substituted for biphosphate of soda, the bead in the inner flame is brownish red. When fused with carbonate of soda on charcoal, the molybdenum is reduced and appears under the form of a grey metal.

Molybdic acid is easily dissolved by alkaline solutions, or their carbonates, forming with these bases very soluble salts; but its compounds with earths and metallic oxides are generally insoluble. Hence most of the earthy and metallic salts occasion precipitates when dropt into the alkaline molybdates: these precipitates even appear in the bimolybdates, provided the solutions be not too dilute.

Nitrate of lead throws down a *white* precipitate; nitrated suboxide of mercury a *yellow* precipitate; solutions of peroxide of iron a *yellow* precipitate; nitrate of silver a *white* precipitate. The precipitates formed by chloride of barium, or chloride of calcium in the bimolybdates are not dissolved by the addition of water, but they dissolve readily in nitric or muriatic acid.

When nitric or muriatic acid is dropt into a molybdate the molybdic acid is thrown down, but it is re-dissolved by an excess of the precipitating acid, and even by water if added in sufficient quantity. Oxalic acid, tartaric acid, acetic acid, and even sulphuric acid, occasion no precipitate when dropt into solutions of alkaline molybdates. They even dissolve the precipitate thrown down by muriatic acid.

Molybdic acid before ignition is easily soluble in acids, but exposure to a red heat renders it insoluble in these bodies. However, bitartrate of potash dissolves it in a boiling heat even after ignition.

Prussiate of potash when dropt into acid solutions of molybdic acid, or into alkaline molybdates mixed with muriatic acid, throws down a reddish brown precipitate, which is redissolved by the addition of ammonia, and the solution becomes light coloured.

Sulphuretted hydrogen gas gives the solutions of molybdic acid a green colour, and throws down a brown precipitate. But sulphohydrate of ammonia produces no precipitate. Yet if we add muriatic acid, a brown precipitate of sulphuret of molybdenum falls.

A piece of zinc put into a molybdate, or solution of molybdic acid, reduces the acid to protoxide of molybdenum. Hence the liquid assumes a dark blackish brown colour. Tin produces the same change.

Molybdate of lead may be dissolved in dilute muriatic acid by means of heat. On cooling the chloride of lead separates in crystals, which may be separated, fused, and weighed. Every 17·5 grains of this chloride are equivalent to 14 grains of oxide of lead.

Evaporate the residual liquid to dryness, and digest the dry mass (which is blue) in nitric acid. It will be converted into a yellowish powder, which is molybdic acid. This acid is to be cautiously dried, ignited, and weighed.

The method of analysis just given is exceedingly easy, but it does not give an accurate result, as we cannot by means of muriatic acid effect a complete separation of the molybdic acid and oxide of lead. If we wish for accurate results we must dissolve the molybdate of lead in muriatic acid, and after separating as much chloride of lead as we conveniently can, we must add sulphohydrate of ammonia in excess to the liquid, and digest for some time in a flask, the mouth of which is stopped by a cork. The rest of the lead will precipitate in the state of sulphuret. Let it be separated by the filter, washed, ignited, and weighed. Every 15 grains of it are equivalent to 14 grains of oxide of lead.

Add muriatic acid to the liquid thus deprived of lead, and set it aside in a warm place till the sulphuretted hydrogen has made its escape. A brown precipitate falls, consisting of sulphuret of molybdenum. Determine the weight of this precipitate, and then digest it in aqua regia till the molybdenum is dissolved, and only sulphur remains. Estimate the weight of this sulphur in the way already explained. Then throw down the sulphuric acid in the liquid by chloride of barium, and determine the weight of the sulphur in it by the method formerly stated. The weight of the sulphur being thus known, and subtracted from the original weight of the sulphuret, leaves the weight of molybdenum which it contained. Every 6 grains of molybdenum are equivalent to 9 grains of molybdic acid.

Sect. 10. *Analysis of Tungstates.*

The only tungstates hitherto observed in the mineral kingdom are the three following; namely,

1. Tungstate of lime.
2. Wolfram, or tungstate of iron and manganese.
3. Tungstate of lead.

Tungstic acid has a yellowish colour, and when heated it assumes a lemon yellow tint. It is fixed, and does not sensibly dissolve in water, or in acids.

With the alkalies it forms salts which are soluble in water. The alkalies and their carbonates dissolve this acid, even after it has been ignited, but the solution is much more difficultly accomplished than that of molybdic acid by the same bodies.

When muriatic acid, nitric acid, or sulphuric acid, is dropt into these solutions, white precipitates fall, composed of tungstic acid, and the precipitating acid. They are not soluble in an excess of the acids employed to throw them down. Phosphoric acid throws down a precipitate which is soluble in an excess of phosphoric acid. Oxalic acid occasions no precipitate. The same remark applies to tartaric and citric acids; but acetic acid throws down a precipitate not soluble in an excess of the acid.

Almost all the compounds of tungstic acid, with the earths and metallic oxides, are insoluble in water. Hence most of the earthy and metallic salts occasion precipitates when dropt into an alkaline tungstate. Chloride of barium, chloride of calcium, nitrate of lead, and nitrate of silver, throw down white precipitates, not soluble in an excess of water.

Sulphuretted hydrogen, or even sulphohydrate of ammonia, occasions no change in the alkaline tungstates. But if we add a little dilute muriatic acid, a light brown precipitate of sulphuret of tungsten is thrown down.

When tungstic acid is fused with biphosphate of soda in the inner flame before the blowpipe, the globule assumes a fine *blue* colour. In the outer flame this colour disappears. If the tungstic acid contain iron, the globule in the inner flame assumes a blood-red colour. When tungstic acid is fused with borax in the inner flame, the colour is yellow or reddish yellow. When fused with carbonate of soda on charcoal, tungstic acid is reduced to the metallic state.

Tungstate of lime, in the state of a fine powder, may be digested in thrice its weight of concentrated nitric acid till almost all the acid is evaporated away. We then add an additional dose of acid, and continue the digestion till the whole is reduced a second time almost to dryness. By this continued digestion the lime will be separated from the tungstic acid, and combined with the nitric acid. If we digest the matter in alcohol, the nitrate of lime will be dissolved, and caustic ammonia will dissolve the tungstic acid. If any thing remain, it will be silica or the stony matter (usually quartz) on which the crystals of tungstate of lime had been deposited.

If we mix the alcoholic solution with sulphate of ammonia, the lime will be thrown down in the state of sulphate. Let it be dried, ignited, and weighed. Every 8·5 grains of it are equivalent to 3·5 grains of lime.

The ammoniacal solution of tungstic acid is evaporated to dryness and ignited. It is now pure tungstic acid.

When tungstic acid is combined, as in *wolfram*, with oxides whose chlorides are soluble in water, it may, according to Wöhler, be analyzed in the following manner:*—Reduce the wolfram to powder, and fuse it with twice its weight of anhydrous chloride of calcium in a platinum crucible. Boil the melted mass in water; the chlorides of iron and manganese are dissolved, but the tungstate of lime remains undissolved. The iron and manganese are separated and determined in the way formerly explained, and the tungstate of lime may be analyzed in the way just described.

I tried this process of Wöhler unsuccessfully. The wolfram remained undecomposed after being kept a considerable time in fusion with chloride of calcium. But the usual mode of analyzing this mineral is fully as easy as this process of Wöhler, even supposing it successful. It is as follows:—

Reduce the wolfram to powder, mix it with twice its weight of carbonate of soda, and fuse the mixture in a platinum crucible. Digest the fused mass in water till every thing soluble be taken up. The oxides of iron and manganese remain undissolved. Dissolve them in muriatic acid, and

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* Poggendorff's Annalen, ii. 345.

separate the iron (after peroxidizement) by benzoate of ammonia, and then throw down the oxide of manganese by carbonate of soda. The alkaline solution contains the tungstic acid, which may be thrown down by muriatic acid, and dissolved in ammonia. The solution being evaporated to dryness, and the residue ignited, leaves pure tungstic acid.

Tungstate of lead may be dissolved in nitric acid, and the solution being rendered as neutral as possible, is to be digested with an excess of sulphohydrate of ammonia. The lead is precipitated in the state of sulphuret. Let it be separated, and estimated in the way already more than once explained.

Add dilute nitric acid to the filtered liquid, and set it aside till all smell of sulphuretted hydrogen is dissipated. The tungsten precipitates in the state of a sulphuret. Let it be separated and washed with water containing some muriatic acid, as pure water dissolves it. Let it be dried and roasted in a gentle heat. It is by this process converted into tungstic acid, which requires only to be weighed.

Sect. 11. *Analysis of Columbates.*

The only columbates at present known in the mineral kingdom are the following five:—

Yttrotantalite, of which there are three species, namely,

1. Dicolumbate of yttria.
2. Triscolumbate of yttria.
3. Tetracolumbate of yttria.—and
4. Fergusonite, or pentacolumbate of yttria.
5. Columbite, or columbate of iron and manganese.

Before the blowpipe columbic acid fuses into a transparent glass with biphosphate of soda, which distinguishes it from silica. With borax also it fuses into a transparent glass, which becomes milk-white on cooling, or at least when gently heated after cooling. This also distinguishes it from silica. With carbonate of soda it unites with effervescence, and when this is done on charcoal, the columbium is not reduced to the metallic state.

Pure columbic acid is a white tasteless powder, which does not redden litmus paper, and after ignition it is insoluble both in acids and alkalies. But it becomes soluble if we fuse it with caustic potash, or soda, or with their carbonates. It dissolves also when fused with bisulphate of potash. If the fused mass be digested in water, the hydrated columbic acid remains undissolved.

This hydrate is insoluble in water, and very little soluble in acids. Sulphuric acid in a concentrated state indeed dissolves a little of it, but it is again precipitated when we dilute the acid with water. Fluoric acid however dissolves it readily. When boiled with binoxalate of potash it is dissolved in considerable quantity. From this solution prussiate of potash throws down a yellow, and tincture of nut galls an orange precipitate.

Hydrated columbic acid dissolves in caustic potash. From this solution the columbic acid is thrown down by muriatic acid, and doubtless by other acids, and is not re-dissolved by an excess of the acid.

When we fuse columbic acid with fixed alkaline carbonates the fused mass does not dissolve in water. But if we wash out the excess of alkali by cold water an alkaline columbate remains, which may be dissolved in boiling water. From this solution the columbic acid is precipitated by simple exposure to the air in consequence of the carbonic acid which is absorbed.

Sulphuretted hydrogen gas produces no change upon columbic acid. If sulphohydrate of ammonia be introduced into the solution of columbic acid in binoxalate of potash, the columbic acid is thrown down by the ammonia, while sulphuretted hydrogen gas is driven off.

The different species of *yttrotantalites* were analyzed by Berzelius in the following manner:—

The mineral being reduced to a fine powder was mixed with six times its weight of bisulphate of potash, also in fine powder, and fused in a large platinum crucible till the whole of the mineral was dissolved in the salt. The melted mass being allowed to cool, it was boiled repeatedly with a large quantity of water, till all the soluble matter was extracted. The columbic acid remained undissolved, while the bases contained in the mineral were dissolved in the excess of sulphuric acid of the bisulphate. To ensure the complete solution of all the bases, the undissolved portion may be boiled for some hours with muriatic acid, and the acid afterwards added to the original solution.

The liquid thus obtained was neutralized by ammonia, and a current of sulphuretted hydrogen gas passed through it. A slight dark brown precipitate fell. After washing, drying, and roasting, this precipitate consists of tungstic acid.

The liquid thus freed from tungstic acid was boiled to drive off the sulphuretted hydrogen, and mixed with some nitric acid in excess to peroxidize the iron which it contained. It was then thrown down by caustic ammonia. The precipitate was white coloured; it was collected on a filter, washed, and dried.

Oxalate of ammonia threw down the lime from the filtered liquid.

The white precipitate was dissolved in nitric acid, and precipitated by oxalate of ammonia. The precipitate was collected on a filter, and washed first with pure water, and afterwards with caustic ammonia. It was now ignited and weighed. Being dissolved in muriatic acid, it left a small quantity of columbic acid. The solution being neutralized and mixed with acetic acid, a little sulphohydrate of ammonia was added till the acid was saturated. The liquid being heated, and put in a warm place, a little dark powder fell, which after ignition proved to be oxide of uranium. The rest of the white precipitate was yttria.

To the liquid thus freed from yttria by oxalate of ammonia, a little caustic ammonia being added, a yellow matter fell. It was re-dissolved in muriatic acid, and thrown down by carbonate of ammonia in considerable excess. It was now pure peroxide of iron.

The analysis of *Fergusonite* is conducted upon nearly the same principles as that of yttrotantalite, but as it contains also oxide of cerium, zirconia, and oxide of tin, some additional steps are necessary.

The columbic acid left, after dissolving the bisulphate of potash off with water, was washed in a solution of sulphohydrate of ammonia, which dissolved a little tin. The solution being evaporated to dryness, and roasted, left grey oxide of tin, easily recognised, because when treated before the blowpipe with carbonate of soda it is reduced to metallic tin.

The liquid from which the columbic acid was separated, was precipitated by caustic ammonia. The precipitate was white, but became tile red after ignition, showing that it contained oxide of cerium. Being dissolved in muriatic acid, chlorine was given out, and when crystals of sulphate of potash were put into the solution, potash-sulphate of cerium precipitated. When dissolved in boiling water, and mixed with caustic potash, the pure oxide of cerium precipitated. It was washed, dried, ignited, and weighed. And the quantity of protoxide of cerium is estimated from the peroxide thus obtained in the way already explained.

The muriatic acid solution, obtained by boiling the impure columbic acid in that acid, was precipitated by caustic ammonia; a brown precipitate fell, which dissolved in boiling muriatic acid, except a trace of columbic acid. The solution being neutralized with ammonia, and mixed, at a boiling temperature, with sulphate of potash, a precipitate fell, which was zirconia. Benzoate of ammonia now threw down a little peroxide of iron.

The liquid from which the oxide of cerium had been precipitated by sulphate of potash, being treated with caustic potash, a precipitate fell, which was ignited. Being dissolved in muriatic acid, it left a little zirconia. The solution in muriatic acid being neutralized by ammonia, and mixed with sulphate of potash, a little more zirconia was thrown down. The liquid thus freed from zirconia was saturated with tartaric acid, and mixed with sulphohydrate of ammonia. The iron was thrown down. This precipitate being dissolved in nitric acid, and the iron thrown down by ammonia, gave the amount of that metal in the state of peroxide.

The residual liquid was evaporated to dryness, and the residue ignited. It was now dissolved in dilute muriatic acid, and precipitated by caustic ammonia. The precipitate, while still moist, was digested in carbonate of ammonia, which dissolved the oxide of uranium. What remained possessed the characters of yttria.*

No remarks are necessary on the mode of analyzing columbite; the process is precisely the same as that for yttrotantalite, only the number of constituents being fewer, the steps are less numerous.

Sect. 12. *Analysis of Titaniates.*

The only titaniates known at present to exist in the mineral kingdom are the nine following:—

1. Titaniate of iron, or menachanite,
2. Iserine,
3. Subsesquititaniate of iron,
4. Crichtonite,
5. Nigrin, or quintotitaniate of iron,

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* See Hartwall's analysis, Kōng. Vet. Acad. Handl., 1828, p. 167.

6. Titaniferous iron ore, consisting of three subspecies, namely,
   (1.) Dititaniate of iron,
   (2.) Tetratitaniate of iron,
   (3.) Pentetitaniate of iron.
7. Pyrochlore,
8. Æschynite, or titaniates of zirconia, cerium, lime, and iron,
9. Sphene.

When titanic acid is fused before the blowpipe with biphosphate of soda in the inner flame, the bead assumes a violet colour, which appears much more conspicuous when the glass cools. The addition of a little tin causes the blue colour to appear sooner. In the outer flame the blue colour disappears. If the titanic acid contains iron the colour becomes in the inner flame blood-red. With borax titanic acid fuses in the outer flame into a colourless glass, which when again heated becomes milk-white. In the inner flame the glass becomes yellow, and by continuing the blast it assumes a blue colour, which becomes much deeper by increasing the quantity of titanic acid. With carbonate of soda on charcoal, titanic acid fuses into a yellow glass with effervescence, which on cooling becomes grey and opaque.*

Pure titanic acid, when precipitated from muriatic acid by boiling, and afterwards ignited, is a white tasteless powder. If it be precipitated by an alkali and then ignited, the colour is light brown, and it is concreted into lumps which have a strong lustre. When its colour is reddish it contains a little iron. When titanic acid is heated it becomes lemon-yellow, but the white colour returns as the acid cools.

Ignited titanic acid is insoluble in all acids. If it be fused with pure alkalies or their carbonates, it combines with them, while the carbonic acid makes its escape. The fused mass has a crystalline texture. Water dissolves the excess of base, and leaves the alkaline titaniate undissolved; it dissolves in muriatic acid by the assistance of a gentle heat. If we dilute the solution and boil it, the greatest part of the titanic acid is precipitated in the state of a white heavy powder. When this precipitate is collected on a filter, the liquid passes through clear as long as it continues acid; but when the water becomes

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* Titanic acid is easily distinguished by the blowpipe from manganese and cobalt. Manganese gives a violet colour with biphosphate of soda in the outer flame, titanic acid in the inner, while cobalt gives a blue colour both in the outer and inner flame.

pure it passes milk-white, and this continues till the whole precipitate makes its way through the filter. This can be prevented by acidulating the water employed for washing the precipitate with muriatic acid.

When titanic acid has been thrown down from its solution by an alkali, it may be washed upon a filter without passing through, and it dissolves again in acids, which is not the case with titanic acid thrown down by boiling.

Potash, soda, ammonia, and their carbonates, throw down white bulky precipitates from the solution of titanic acid in muriatic acid. The precipitates do not dissolve in an excess of the precipitating alkalies, but readily in an excess of muriatic acid.

When the muriatic solution of titanic acid contains as little free muriatic acid as possible, dilute sulphuric acid, arsenic acid, phosphoric acid, tartaric acid, and oxalic acid (especially this last) throw down white precipitates. All these precipitates are re-dissolved in an excess of the precipitating acids, or in muriatic acid. Nitric acid, acetic acid, and succinic acid occasion no precipitates.

The tincture of nutgalls throws down an *orange-red* precipitate, which is characteristic of titanium. Prussiate of potash throws down a precipitate having very nearly the same colour.

Sulphuretted hydrogen occasions no precipitate; but sulphohydrate of ammonia throws down a white precipitate merely in consequence of the ammonia which it contains.

If a piece of zinc be put into a solution of titanic acid in muriatic acid, the liquid assumes a blue colour, while hydrogen gas is disengaged. After a time a blue precipitate falls, which gradually assumes a white colour. Iron or tin acts in the same way as zinc.

All the titaniates, so far as known, appear to be soluble in muriatic acid.

The analysis of minerals containing titanic acid is attended with so many difficulties, that chemists have not yet been able to overcome them all. We owe much on this subject to the researches of Berzelius and H. Rose.

We shall begin with *titaniferous iron ore*, which, containing both oxides of iron, requires particular management.

Mosander, to whom we are indebted for the latest and best analysis of titaniferous iron ores,* took the following mode to

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* Köng. Vet. Acad. Handl., 1829. p. 221.

determine the state of oxidizement of the iron:—A quantity of the ore, reduced to a fine powder, was introduced into a porcelain tube on a porcelain tray. To the tube was attached an apparatus for the evolution of hydrogen gas, already described in a former part of this work. The tube being filled with hydrogen gas, the porcelain tray with the ore was heated to redness. The oxygen of the iron at that temperature united to the hydrogen, and made its escape in the form of water. The process was continued for half an hour after all evolution of water was at an end, and it lasted altogether from two and a half to three hours. When the apparatus was cold, the ore was taken out and weighed. The loss of weight gave the quantity of oxygen disengaged from the iron.

Diluted muriatic acid being now poured upon the ore, the iron dissolved with the evolution of hydrogen. Towards the end of the process it is requisite to add stronger muriatic acid to dissolve out the whole of the iron. The titanic acid remains behind undissolved.

The muriatic acid solution contains all the iron, and the other constituents which (besides titanic acid) may be present. It is digested with some nitric acid to peroxidize the iron. The peroxide of iron is now precipitated with the usual precautions by benzoate of ammonia. Knowing the weight of the peroxide of iron thus obtained, it is easy to deduce the weight of iron, and as the weight of the oxygen in combination with that iron had been already determined, we obviously have the means of ascertaining how much of the iron was in the state of protoxide, and how much in that of peroxide.

The liquid thus freed from iron, is to be evaporated to dryness, and afterwards ignited to drive off the ammoniacal salts. The dry residue is to be digested in muriatic acid. Should any thing remain undissolved, it is to be examined by the blowpipe. It was found on one occasion, by Mosander, to be a mixture of yttria and oxide of cerium.

From the muriatic acid solution, let the manganese be thrown down by sulphohydrate of ammonia.

The lime is to be thrown down by oxalate of ammonia.

Let the residual liquid be evaporated to dryness, and ignited, to drive off the ammoniacal salts. If we now mix it with sulphuric acid, evaporate to dryness, and expose the residual salt to incipient ignition, we shall find it to consist of pure sulphate of magnesia, from which the magnesia may be extracted, and its weight determined in the usual way.

The undissolved titanic acid is to be digested in sulphuric acid, mixed with its own weight of water. By repeated boiling in this acid liquid, the whole titanic acid is dissolved, and what remains is silica.

Let the sulphuric acid solution be evaporated, till as much as possible of the excess of the sulphuric acid is driven off. Dilute with water, and add some sulphohydrate of ammonia. Occasionally a slight precipitate of sulphuret of tin falls. The titanic acid is still contaminated with about one per cent. of iron and manganese.

The same process of analysis will answer for *menachanite*, *iserine*, *subsesquititaniate of iron*, *Crichtonite*, and *nigrin*.

Pyrochlore, so far as we are acquainted with its constitution, is a compound of titanic acid with lime, and oxides of uranium, cerium, manganese, and iron. It was analyzed by M. Wöhler, in the following way:—

It was heated to redness in a small retort made from a glass tube, to determine the quantity of water. The liquid driven off had a sour taste, and contained traces of an acid, probably the fluoric.

A given weight of the mineral reduced to a fine powder, was digested for a long time in dilute sulphuric acid, till the whole was reduced to a white homogeneous looking mass. During this process, some fluoric acid was driven off. The surplus of sulphuric acid was evaporated off, and the bluish-green mass remaining was boiled in a great quantity of water. By this process, the titanic acid was thrown down, while the gypsum was dissolved. The solution was filtered off from the white heavy precipitate, which was well washed.

From the liquid, caustic ammonia threw down a small quantity of brownish-yellow matter. It was heated in caustic potash, and the liquid being saturated with muriatic acid and mixed with ammonia, let fall no precipitate. Hence the pyrochlore contains no alumina. The precipitate being digested in carbonate of ammonia, became dark-brown. The ammoniacal solution was yellow. When diluted with water and heated, it deposited yellow flocks. These flocks before the blowpipe, showed the characters of a mixture of oxides of cerium and tin. The yellow solution being evaporated to dryness, left a little peroxide of uranium. The portion undissolved in carbonate of ammonia, dissolved in muriatic acid, and was found to consist of oxide of cerium, mixed with some oxide of iron, and a trace of oxide of manganese.

The ammoniacal liquid filtered from the brownish-yellow precipitate, was mixed with oxalate of ammonia, which threw down the lime.

The residual liquid was evaporated to dryness and roasted, to drive off the ammoniacal salts. A greyish substance remained which dissolved in water. Phosphate of soda and ammonia detected in it a trace of magnesia, but it consisted almost entirely of sulphate of manganese.

The white undissolved substance, considered as titanic acid, was digested for twenty-four hours in sulphohydrate of ammonia while still moist. It assumed a leek-green colour, derived from a minute trace of iron. The sulphohydrate of ammonia was separated and evaporated to dryness. The residual matter was ignited in an open vessel. It was a dirty yellow powder, which being mixed with carbonate of soda, and heated on charcoal before the blowpipe, yielded globules of tin.

The titanic acid thus treated, was dried, ignited, and weighed. It contained merely a trace of iron, but it might contain both zirconia and columbic acid. To determine whether either of these bodies was present, the following experiments were made:—

A portion was fused with bisulphate of potash. The fusion was complete, and the globule perfectly transparent; a proof that the titanic acid contained no silica. When put into water it became milk-white, and as it dissolved, a white powder separated, which was collected and washed on a filter. From the filtered liquid, ammonia threw down some white flocks, which possessed the characters of titanic acid. The white powder being digested in concentrated muriatic acid, was completely dissolved, a proof that the titanic acid contained no columbic acid, which is insoluble in muriatic acid.

The muriatic acid solution being boiled, deposited a quantity of pure titanic acid. The residual liquid being dropped into a solution of caustic potash, gave a farther precipitate of titanic acid, which was completely soluble in an excess of the alkali. From this and some other experiments, the absence of zirconia was inferred.*

The analysis of æschynite may be conducted nearly upon the same plan; only, as it contains zirconia, that earth will require to be separated from the titanic acid by the methods already pointed out.

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* Poggendorff's Annalen, vii. 420.

Sphene is a compound of titanic acid, silica, and lime. It was analyzed by Klaproth in the following way:

Being reduced to a fine powder, it was digested in muriatic acid, by which a considerable portion was dissolved. The undissolved portion was mixed with five times its weight of carbonate of potash, and fused. The fused mass was digested in muriatic acid, which dissolved it completely. The two muriatic acid solutions were mixed and evaporated to dryness. The dry residue being digested in water acidulated with muriatic acid, the whole was thrown on a filter. The silica was left upon the filter, washed, dried, ignited, and weighed.

The muriatic acid solution, thus freed from silica, was precipitated by caustic ammonia. The precipitate was titanic acid. It was washed, dried, ignited, and weighed.

Nothing now remained in solution but the lime, which Klaproth threw down by means of carbonate of potash.*

Various other modes of analyzing this mineral will easily suggest themselves to those who have made themselves familiar with the preceding part of this work.

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* Beiträge, v. 243.

NOTE.

In the table of fossil plants, page 265, no explanation is given of the abbreviations put after most of the species. They refer to figures of the species. Br. denotes the plates in the *Histoire des vegetaux fossiles* by M. Adolphe Brongniart. L. and H. refer to the plates in the British fossil flora of Messrs. Lindley and Hutton.

The arterisk (*) prefixed to a genus in the table indicates that living plants belonging to that genus still continue to exist.

In the table of animal fossils that follows in page 290 of the same volume, an asterisk (*) after the name of a species indicates that the species exists in more than one formation. Those species after which no asterisk occurs have been observed only in one formation.

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The Roman numerals denote the volume. When there are no Roman numerals the first volume is indicated.

THE END.

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